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Computer Oriented Stability Analysis Of Reservoir Slopes

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TECHNICAL REPORT NO. 17

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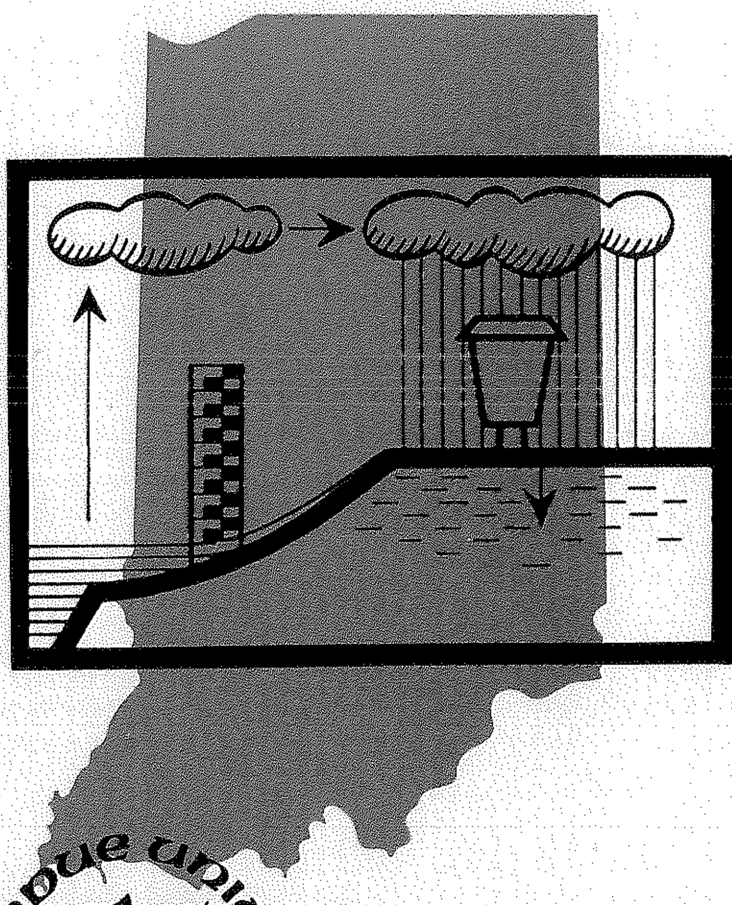

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Purdue University Water Resources Research Center

Technical Report No. 17

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This report is essentially a reproduction of a thesis entitled "Computer Oriented Slope Stability Analysis by Method of Slices" and submitted to the Faculty of Purdue University by Mr. Robert Kerner Carter in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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ABSTRACT

This report is the first for project No. OWRR A-009-IND (Agreement numbers 14-01-0001-1633; 01-0001-3014; 31-0001-3214) entitled "Fluctuation of Reservoir Levels and the Related Cause of Landslides."

The purpose of this particular part of the research was the development of a computer-assisted system of stability analysis for specific reservoir slopes. The versatility of the developed programs includes accommodations for variable ground surface and profile characteristics, both uniform and concentrated external boundary loadings, spatial variations in water pressure, and irregular as well as circular shaped failure surfaces.

Several limiting equilibrium analyses by methods of slices have been reviewed. One of these, the modified Bishop technique, previously considered applicable only to circular failure surfaces, was modified to include irregular shaped surfaces.

The programs have been written in elementary Fortran IV language. There are currently five main programs and eleven integrated supporting routines. Conversion of the programs to small computer systems is considered highly practical.

INTRODUCTION

During the planning and development of reservoirs, a condition generally not assessed is the stability of the slopes bounding the reservoir pool. Accordingly, the consequences of reservoir filling and fluctuations, on developments on or adjacent to these slopes, are unknown. Although failures of reservoir slopes are not very common, the results can be catastrophic in terms of both personal property and loss of life (Kiersch, 1964).[1] The intent of this research project is to develop a systematic technique for determining the potential instability of reservoir slopes.

The technique encompasses two levels of investigation both of which are computer oriented. First, it is desired to locate the potentially troublesome areas by a general-level system. By examining a number of regional factors, e.g., hydrology, geology, and topography, for the areas bounding a proposed reservoir, zones with susceptibility to slope instability can be located. Secondly, a detailed analysis, a specific-level system, is needed for any zone earmarked by the general-level system, to ascertain whether instability of an individual slope would indeed exist. The specific-level system should be sufficiently versatile to accommodate irregular slopes, complexities of the

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1. See entries in the List of References, page 50.

subsurface and failure surface geometry, conditions of variable internal water pressures and of ground surface boundary loadings.

This report concerns itself with the second phase of the research project, the development of the specific-level, computer-assisted system for the prediction of reservoir slope stability.

METHODS OF LIMITING EQUILIBRIUM FOR SLOPE STABILITY ANALYSIS

Two approaches have been developed for assessing the stability of slopes by the limiting equilibrium method (Harr, 1966; Romani, 1970). In the first, incipient failure is assumed at all points in the mass. In the second, failure is assumed along a particular surface in a material of reduced strength. The minimum strength reduction factor, also called the factor of safety (F), is generally determined by iteration. Each trial solution of F involves an application of the conditions of statical equilibrium for both the internal and external forces.

The second method is commonly applied to practical problems. It is assumed that the factor of safety has a single value along any trial failure surface, and is a simple ratio of the shearing resistance available along this surface to the shearing resistance required to satisfy statics.

In the common approaches to stability analysis, it is important to realize that the strain characteristics of the material are of no consequence. Also, local zones of overstress may exist even though a "reasonable" value of the factor of safety may be predicted (Romani, 1970).

For analyzing slopes which are characterized by distributions of pore pressures, or by variations in the unit weight, strength properties of the material, or by boundary forces, the method of slices is convenient. Given an assumed failure surface, the entire free body is divided into a number of vertical-sided increments, as shown in Figure 1, and static equilibrium is applied to each slice. However, barring an unusually simple material, a unique solution is not possible due to the indeterminancy of the slice equilibrium. Figure 2 shows a typical slice for the generalized case involving boundary water. Table 1 lists the unknowns per slice, and the total unknowns for the entire free body, assuming n number of slices. The total number of unknowns is (5n-2), and, using the three statical equations per slice, the total number of equations is 3n. The problem is therefore (2n-2) indeterminate, and additional assumptions are required to solve it.

Taylor Solution

One of the earliest solutions, originally proposed by Fellinius (1927) and later advanced by Taylor (1940), assumes that the resultant of the side forces, effective or total, on each side of the slice acts parallel to the slice base.[1] Therefore, it is possible to sum forces in the direction normal to the slice base,

$$\Sigma F_n = 0$$

$$N' + U_\alpha = W \cos \alpha + U_\beta \cos (\alpha - \beta) \qquad 1$$

This method and its assumptions are particularly suited to failure surfaces that are circular in shape, since in summing moments about the

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1. The assumption generally produces a contradiction of the basic law of equality of action and reaction, when adjacent slices are considered.

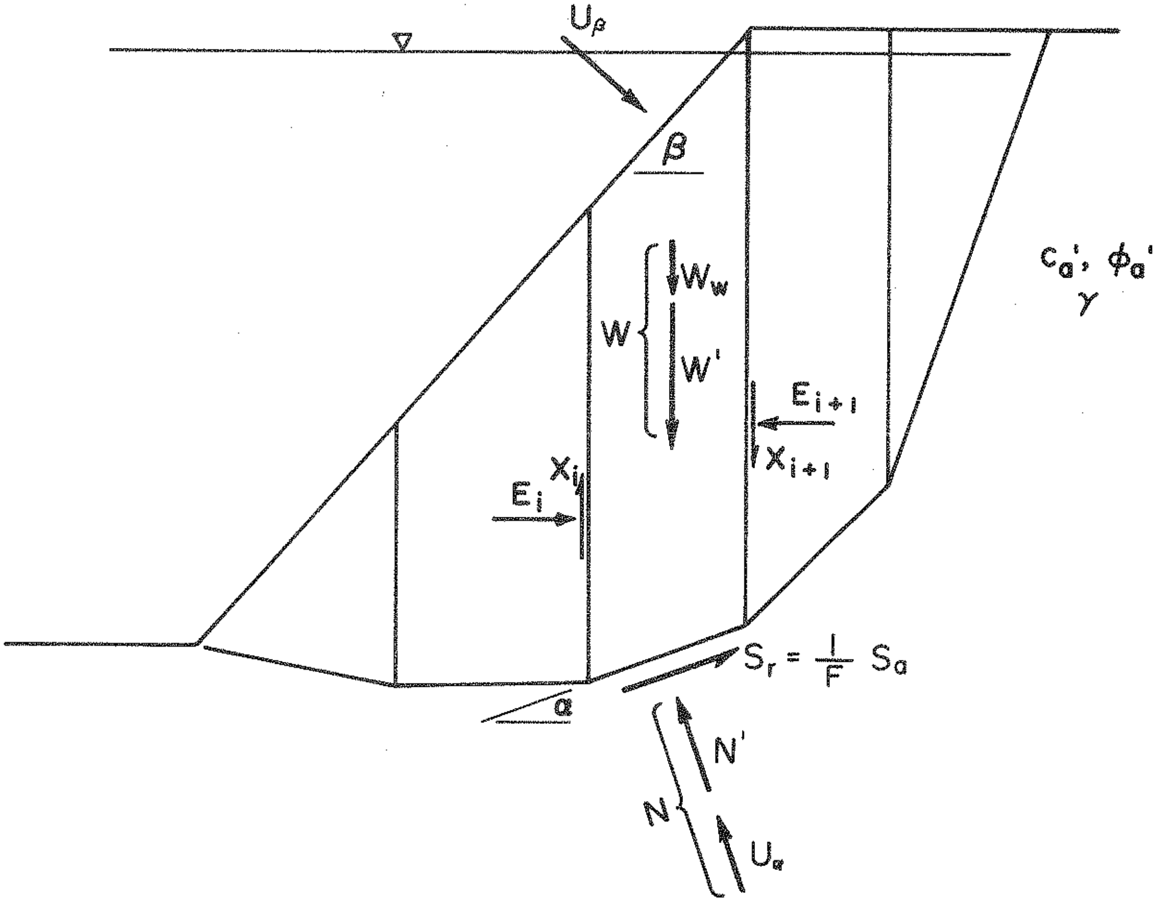

Figure I - Free Body for an Assumed Failure Surface

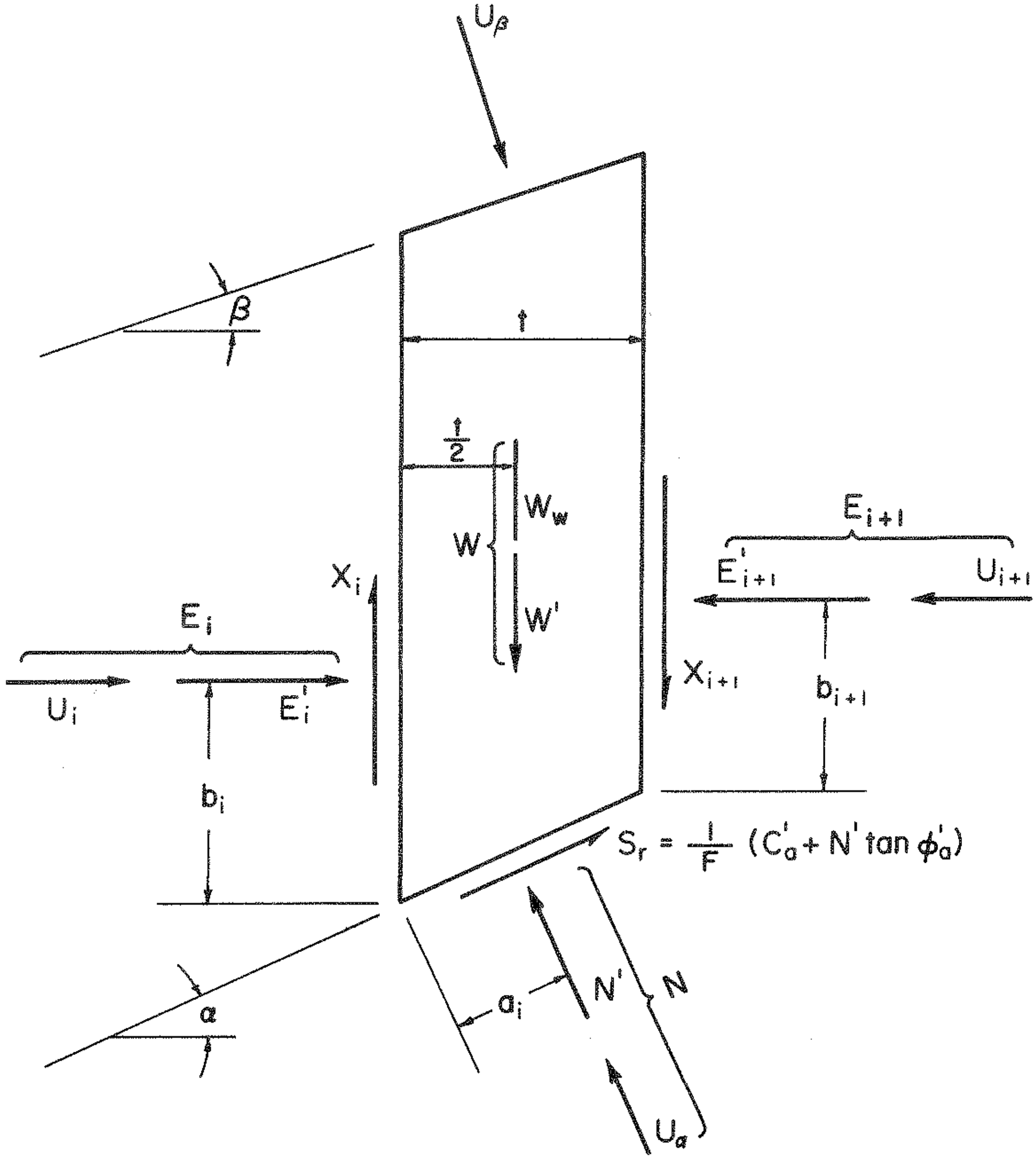

Figure 2 - Typical Slice Free Body

Table 1

Unknowns in Method of Slices

Unknowns	Number/Slice	Total
E	2	n - 1
X	2	n - 1
N'	1	n
b	2	n - 1
a	1	n
F	1	1
		5n - 2

n = number of slices

center of the circle, all forces acting normal to the failure surface would not appear in the equation.

Therefore, summing about the point[1] 0 all moments shown in Figure 3 for all slices, gives,

$$\Sigma\ (W + U_\beta \cos\beta)\ R \sin\alpha = \Sigma\ S_r R + \Sigma\ U_\beta \sin\beta\ (R\cos\alpha - h) \qquad 2$$

where h represents the average height of a slice.

Substituting the Mohr-Coulomb strength relationship,

$$\tau_r = \frac{1}{F}\tau_a = \frac{1}{F}(c'_a + \sigma' \tan\phi'_a)$$

in terms of forces,

$$S_r = \frac{1}{F} S_a = \frac{1}{F}(C'_a + N' \tan\phi'_a) \qquad 3$$

factoring R, a constant, from each summation term in Equation 2, and solving for F,

$$F = \frac{\Sigma\ (C'_a + N' \tan\phi'_a)}{\Sigma\ (W + U_\beta \cos\beta)\sin\alpha - \Sigma\ U_\beta \sin\beta\ (\cos\alpha - \frac{h}{R})} \qquad 4$$

Now, substitute into Equation 4 the expression for N', Equation 1,

$$F = \frac{\Sigma\ \{C'_a + [W\cos\alpha + U_\beta \cos(\alpha-\beta) - U_\alpha] \tan\phi'_a\}}{\Sigma\ (W + U_\beta \cos\beta)\sin\alpha - \Sigma\ U_\beta \sin\beta\ (\cos\alpha - \frac{h}{R})} \qquad 5$$

1. Since the side force assumption violates equilibrium, different centers for moments will produce a variety of solutions.

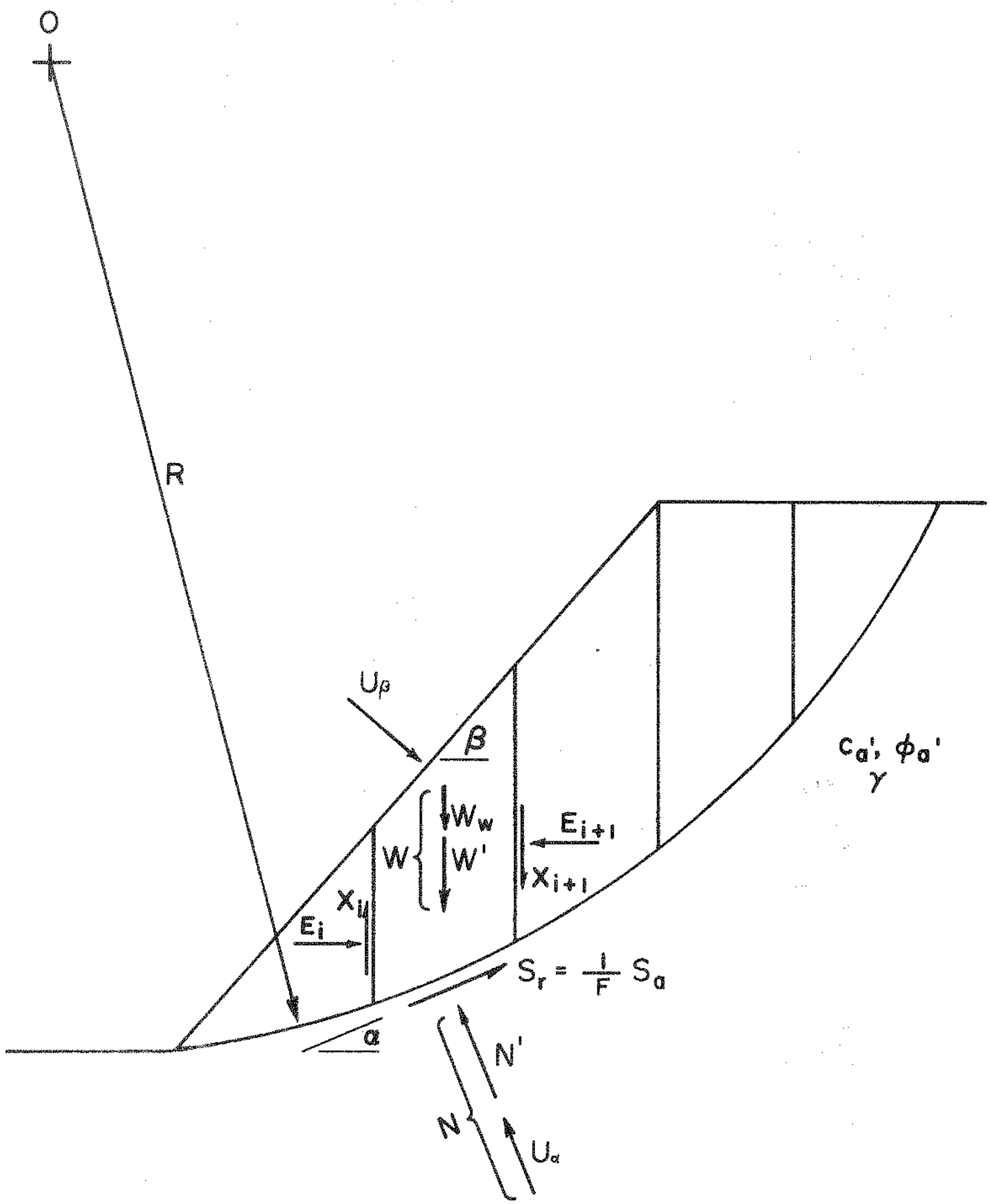

Figure 3 - Free Body for an Assumed Circular Failure Surface

Bishop Method

A method which satisfies force equilibrium of each slice and moment equilibrium of the entire free body was proposed by Bishop (1955). Although the following development is for an assumed circular failure surface, the general theory is applicable to irregular surfaces as well.

Summing forces in the vertical direction on the slice in Figure 2, gives,

$$\Sigma F_v = 0$$

$$(N' + U_\alpha) \cos \alpha + S_r \sin \alpha + X_i = W + U_\beta \cos \beta + X_{i+1} \qquad 6$$

Now, substitute the Mohr-Coulomb effective stress relationship, Equation 3, and solve for N'.

$$N' = \frac{W + U_\beta \cos \beta - U_\alpha \cos \alpha + X_{i+1} - X_i - \dfrac{C'_a \sin \alpha}{F}}{\cos \alpha + \dfrac{\sin \alpha \tan\phi'_a}{F}} \qquad 7$$

Backsubstituting Equation 7 into Equation 4, the moment expression, and simplifying,

$$F = \frac{\Sigma \left\{ \dfrac{C'_a + (W + U_\beta \cos \beta - U_\alpha \cos \alpha + X_{i+1} - X_i) \sec \alpha \tan \phi'_a}{1 + \dfrac{\tan \alpha \tan \phi'_a}{F}} \right\}}{\Sigma \{\sin \alpha \, (W + U_\beta \cos \beta)\} - \Sigma \{U_\beta \sin \beta \, (\cos \alpha - \frac{h}{R})\}} \qquad 8$$

Since X and E are internal forces, the following conditions must hold,

$$\Sigma (X_{i+1} - X_i) = 0 \qquad 9a$$

$$\Sigma (E'_{i+1} - E'_i) = 0 \qquad 9b$$

Now, resolve forces in the tangential direction on the slice, Figure 2,

$$S_r + X_i \sin\alpha + (E'_i + U_i)\cos\alpha =$$

$$W \sin\alpha + X_{i+1} \sin\alpha + (E'_{i+1} + U_{i+1})\cos\alpha \qquad 10$$

or

$$E'_{i+1} - E'_i = \frac{S_r - (W + X_{i+1} - X_i)\sin\alpha}{\cos\alpha} \qquad 11$$

Substituting S_r, Equation 3, and taking the sum over all slices yields,

$$\Sigma\,(E'_{i+1} - E'_i) = \Sigma\,\{m \sec\alpha - (W + X_{i+1} - X_i)\tan\alpha\} \qquad 12$$

where

$$m = \frac{C'_a + (W + U_\beta \cos\beta - U_\alpha \cos\alpha + X_{i+1} - X_i)\sec\alpha \tan\phi'_a}{1 + \dfrac{\tan\alpha \tan\phi'_a}{F}}$$

Or from Equation 9b,

$$\Sigma\,\{m \sec\alpha - (W + X_{i+1} - X_i)\tan\alpha\} = 0 \qquad 13$$

Bishop suggests an iterative solution in which Equation 9a is used in assuming a set of X forces, Equation 8 is applied to find the corresponding F, and Equation 13 is used to provide relative corrections to the assumed X forces. A solution is achieved when the three equations are simultaneously satisfied.

The solution however does not satisfy complete statics. Each slice will be in vertical and tangential equilibrium, and the entire free body will be in moment equilibrium. Yet, each slice will not necessarily be in moment equilibrium. Due this deficiency of statics, a range of solutions exists for a number of possible $(X_{i+1} - X_i)$ arrays.

Modified Bishop Method

Realizing that the iteration for what has been termed the "complete Bishop analysis" is quite tedious, Bishop suggested simplifying the solution by assuming that the shear forces acting on the vertical sides of each slice are equal in magnitude and opposite in direction, thereby reducing Equation 8 to an expression of only one unknown,

$$F = \frac{\Sigma \left\{ \dfrac{C'_a + (W + U_\beta \cos \beta - U_\alpha \cos \alpha) \sec \alpha \tan \phi'_a}{1 + \dfrac{\tan \alpha \tan \phi'_a}{F}} \right\}}{\Sigma \{(W + U_\beta \cos \beta) \sin \alpha\} - \Sigma \{U_\beta \sin \beta \, (\cos \alpha - \frac{h}{R})\}} \qquad 14$$

Bishop (1955) examined this assumption for a number of simple cases and found a difference of only approximately 1% (with respect to the unmodified method) in the factor of safety. Since the modified Bishop method requires a gross assumption of statics, like the Taylor method, it has also been considered limited to circular failure surfaces.

Morgenstern and Price Method

In the Morgenstern and Price (1965) method, not only are the normal and tangential force equilibriums ensured but also moment equilibrium for each slice. The simplifying assumption is made regarding the relationship between X and E.

$$X = \lambda \, f(x) \, E \qquad 15$$

where f(x) is an assumed normalized function supplied by the user.

Again, since no unique solution exists, iteration for a solution is necessary. By a systematic technique, boundary conditions are met, and values of F and λ are found as the solution for a given f(x).

Although the developers reported that the factor of safety is relatively insensitive to f(x), a great deal of work is indeed necessary, and Whitman and Bailey (1967) concluded that for most projects the simpler techniques are justified.

Bell Method

More recently, Bell (1968) presented another technique which is applicable to irregular surfaces. Bell develops the three equations of equilibrium for the entire free body rather than for each of n slices. In addition to the factor of safety, the distribution of normal stress acting on the assumed failure surface is unknown. The distribution is assumed to be,

$$\sigma_n = C_1 Wt + C_2 f\ (x_i, y_i, z_i) \qquad 16$$

where

W = weight of slice

t = thickness of slice

$$f = \sin 2\pi \left(\frac{x_n - x_i}{x_n - x_o}\right)$$

x_i = right interslice x coordinate

y_i = right interslice ground surface y coordinate

z_i = right interslice slip surface y coordinate

C_1 and C_2 are unknowns

Assuming the normal stress distribution leaves only three unknowns. By linear algebra techniques, a clever solution from iteration is presented. But, just as in the Morgenstern and Price technique, the result is dependent on f.

PROPOSED METHOD OF ANALYSIS FOR IRREGULAR SURFACES

Neither the Taylor method nor the modified Bishop method of analysis satisfy statics in the gross sense. The key assumption made in the Taylor analysis is summation of forces on a slice normal to its base with cancellation of all side force components in this direction. The unique point that can then be used for summing external moments and comparing the factor of safety of different assumed failure surfaces is indeed the point of intersection of the normal lines to each slice base. Consequently, the Taylor analysis, by virtue of the key assumption, is limited to circular failure surfaces, the unique point of moment summation being the center of the circle.

On the other hand, the critical assumption made in the modified Bishop method of analysis is summation in the vertical direction of the forces acting on a slice with cancellation of side forces in this direction. In the original development, the assumed failure surface was circular, and the point used for summation of external moments and, hence, comparison of the factors of safety for different assumed surfaces, was the circle center. However, the center of the circle is not the unique point that should be used for external moment equilibrium. Consider the following development.

Referring to Figure 4, sum moments of all external forces for all slices about the arbitrary point 0, resolving each force into a horizontal and vertical component.[1]

$$\Sigma\ (N' + U_\alpha)(\bar{y} \sin \alpha - \bar{x} \cos \alpha) + \Sigma\ W\ \bar{x} + \Sigma\ U_\beta\ (\bar{x} \cos \beta - \bar{a} \sin \beta)$$

$$- \Sigma\ S_r\ (\bar{x} \sin \alpha + \bar{y} \cos \alpha) = 0 \quad , \qquad 17$$

where $\bar{a} = \bar{y} - h$

Applying the associative law of addition, Equation 17 may be written,

$$\Sigma\ \{(N' + U_\alpha)(\bar{y} \sin \alpha - \bar{x} \cos \alpha) + W\ \bar{x} + U_\beta\ (\bar{x} \cos \beta - \bar{a} \sin \beta)$$

$$- S_r\ (\bar{x} \sin \alpha + \bar{y} \cos \alpha)\} = 0 \qquad 18$$

Substitute into Equation 18, S_r, the Mohr-Coulomb effective stress relationship, Equation 3, and rearrange,

$$\Sigma\ \{N'\ (\bar{y} \sin \alpha - \bar{x} \cos \alpha - \bar{x} \frac{\sin \alpha}{F} \tan \phi'_a - \bar{y} \frac{\cos \alpha}{F} \tan \phi'_a)$$

$$+ W\ \bar{x} - \frac{C'_a}{F} (\bar{x} \sin \alpha + \bar{y} \cos \alpha) + U_\alpha\ (\bar{y} \sin \alpha - \bar{x} \cos \alpha)$$

$$+ U_\beta\ (\bar{x} \cos \beta - \bar{a} \sin \beta)\} = 0 \qquad 19$$

Now, substitute the complete expression for N', Equation 7.

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1. The forces X_i and E_i being internal to the sliding free body do not produce an external moment.

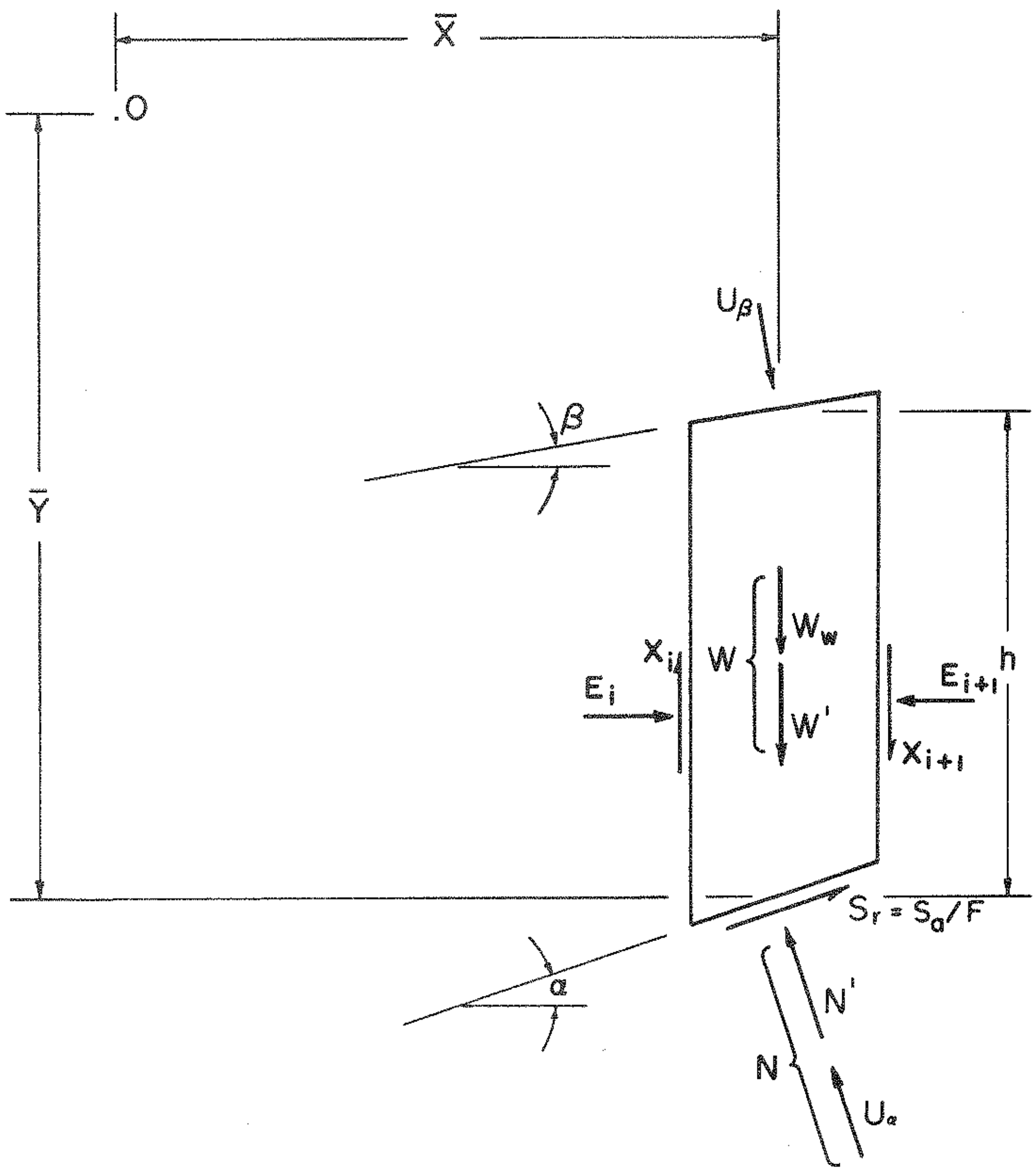


Figure 4 - External Forces for a Slice with Reference to an Arbitrary Center

$$\Sigma \{[\frac{F(W + U_\beta \cos \beta - U_\alpha \cos \alpha + \Delta X) - C'_a \sin \alpha}{F \cos \alpha + \sin \alpha \tan \phi'_a}]$$

$$(\bar{y} \sin \alpha - \bar{x} \cos \alpha - \bar{x} \frac{\sin \alpha \tan \phi'_a}{F} - \bar{y} \frac{\cos \alpha \tan \phi'_a}{F})$$

$$+ W \bar{x} - \frac{C'_a}{F} (\bar{x} \sin \alpha + \bar{y} \cos \alpha) + U_\alpha (\bar{y} \sin \alpha - \bar{x} \cos \alpha)$$

$$+ U_\beta (\bar{x} \cos \beta - \bar{a} \sin \beta)\} = 0 \qquad 20$$

$$\text{where } \Delta X = X_{i+1} - X_i$$

Using the least common denominator,

$$F(F \cos \alpha + \sin \alpha \tan \phi'_a),$$

collect like terms in Equation 20.

$$\Sigma \{[W (F^2 \bar{y} \sin \alpha - F \bar{y} \cos \alpha \tan \phi'_a) - C'_a F\bar{y} + U_\alpha F\bar{y} \tan \phi'_a$$

$$+ U_\beta (F^2 \bar{y} \cos \beta \sin \alpha - F^2 \bar{a} \sin \beta \cos \alpha - \bar{y} F \cos \beta \cos \alpha \tan \phi'_a$$

$$- \bar{a} F \sin \alpha \sin \beta \tan \phi'_a)$$

$$+ \Delta X (F^2 \bar{y} \sin \alpha - F^2 \bar{x} \cos \alpha - F \bar{x} \sin \alpha \tan \phi'_a - F \bar{y} \cos \alpha \tan \phi'_a)]$$

$$\div (F^2 \cos \alpha + F \sin \alpha \tan \phi'_a)\} = 0 \qquad 21$$

Cancelling F from each term, dividing through by cos α, and transposing the ΔX term gives,

$$\Sigma\ \{(W\bar{y}\ (\tan\ \phi_a' - F\ \tan\ \alpha) + C_a' \frac{\bar{y}}{\cos\ \alpha} - U_\alpha \bar{y}\ \frac{\tan\ \phi_a'}{\cos\ \alpha}$$

$$- U_\beta\ (F\bar{y}\ \cos\ \beta\ \tan\ \alpha - F\bar{a}\ \sin\ \beta - \bar{y}\ \cos\ \beta\ \tan\ \phi_a'$$

$$- \bar{a}\ \sin\ \beta\ \tan\ \alpha\ \tan\ \phi_a')]$$

$$\div\ (F + \tan\ \alpha\ \tan\ \phi_a')\}$$

$$= \Sigma\ \{\Delta X\ (\frac{F\bar{y}\ \tan\ \alpha - F\bar{x} - \bar{x}\ \tan\ \alpha\ \tan\ \phi_a' - \bar{y}\ \tan\ \phi_a'}{F + \tan\ \alpha\ \tan\ \phi_a'})\qquad 22$$

Simplifying the ΔX coefficient and the U_β coefficient using,

$\bar{k} = 1 - \frac{h}{\bar{y}}$,

$$\Sigma\ \{[W\bar{y}\ (\tan\ \phi_a' - F\ \tan\ \alpha) + C_a' \frac{\bar{y}}{\cos\ \alpha} - U_\alpha\ \bar{y}\ \frac{\tan\ \phi_a'}{\cos\ \alpha}$$

$$- U_\beta\ F\bar{y}\ (\cos\ \beta\ \tan\ \alpha - \bar{k}\ \sin\ \beta)$$

$$+ U_\beta\ \tan\ \phi_a'\ \bar{y}\ (\cos\ \beta + \bar{k}\ \sin\ \beta\ \tan\ \alpha)]$$

$$\div\ (F + \tan\ \alpha\ \tan\ \phi_a')\}$$

$$= \Sigma\ \Delta X\ [\ \frac{\bar{y}\ (F\ \tan\ \alpha - \tan\ \phi_a')}{F + \tan\ \alpha\ \tan\ \phi_a'} - \bar{x}]\qquad 23$$

Factoring $\bar{y}$ and rearranging terms yields,

$$\Sigma\ \bar{y}\ \{\tan\phi'_a\ [W - \frac{U_\alpha}{\cos\alpha} + U_\beta\ (\cos\beta + \bar{k}\sin\beta\tan\alpha)$$

$$+ \frac{C'_a}{\cos\alpha} - F\ [W\tan\alpha + U_\beta\ (\cos\beta\tan\alpha - \bar{k}\sin\beta]\}$$

$$\div\ (F + \tan\alpha\tan\phi'_a)$$

$$= \Sigma\ \bar{y}\ \Delta X\ [\ \frac{\tan\alpha - \frac{\tan\phi'_a}{F}}{1 + \frac{\tan\alpha\tan\phi'_a}{F}} - \frac{\bar{x}}{\bar{y}}\ ] \qquad 24$$

If the "true" set of forces ΔX were known, the solution of Equation 24 would give a value of F compatible with vertical equilibrium of each slice and moment equilibrium of the entire free body at all points in the x-y plane. Since the "true" set of forces ΔX cannot be determined without further assumptions, consider the consequence of applying the modified Bishop assumption, namely $\Delta X = 0$, to Equation 24.

Rewriting Equation 24 with this assumption,

$$\Sigma\ \bar{y}\ (\frac{A_1 - F\ A_2}{F + A_3}) = 0 \qquad 25$$

where

$$A_1 = \frac{C'_a}{\cos\alpha} + \tan\phi'_a\ [W - \frac{U_\alpha}{\cos\alpha} + U_\beta\ (\cos\beta + \bar{k}\sin\beta\tan\alpha)]$$

$$A_2 = W\tan\alpha + U_\beta\ (\cos\beta\tan\alpha - \bar{k}\sin\beta)$$

$$A_3 = \tan\alpha\tan\phi'_a$$

The value of F resulting from the solution of Equation 25 is no longer a function of the material properties and the shape of the slip surface <u>only</u>, but also of the vertical position of the point for which the external moment equation is written. In other words, the factor of safety will vary as y_o (the y coordinate of the moment center) is varied, and will be a constant as x_o (the x coordinate of the moment center) is varied with y_o constant.

As y_o increases, the difference between $\bar{y}_i$ becomes smaller, and hence $\bar{y}_i$ approaches a constant. For this limiting condition, $\bar{y}$ can be factored out of the summation in Equation 25 giving Equation 26.

$$\Sigma \left(\frac{A_1 - F\, A_2}{F + A_3} \right) = 0 \qquad 26$$

where

$$A_1 = \frac{C'_a}{\cos \alpha} + \tan \phi'_a \left[W - \frac{U_\alpha}{\cos \alpha} + U_\beta(\cos \beta + \sin \beta \tan \alpha)\right]$$

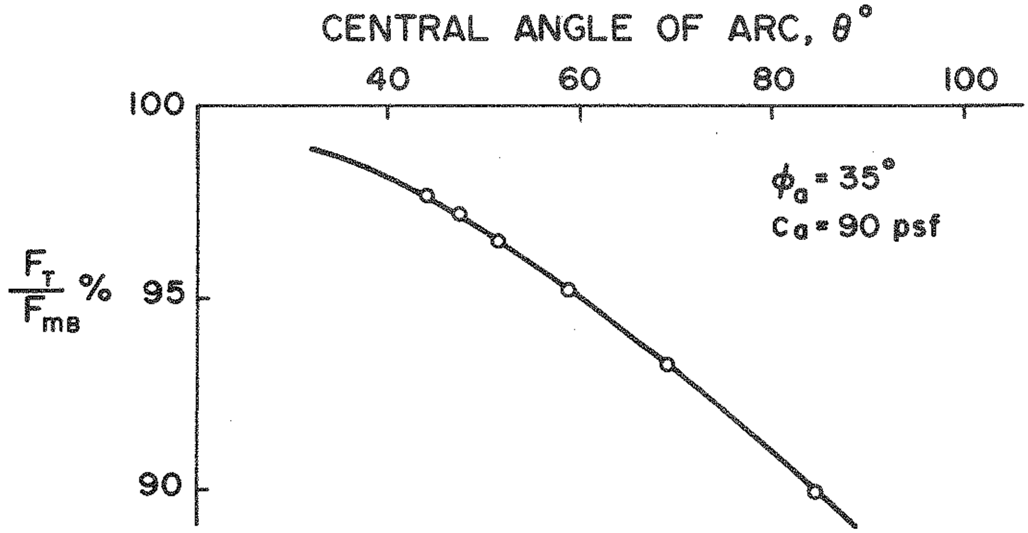
$$A_2 = W \tan \alpha + U_\beta \,(\cos\beta \tan \alpha - \sin \beta)$$

$$A_3 = \tan \alpha \tan \phi'_a$$

Equation 26, which is no longer dependent upon the position of the moment center, can be used for circular as well as irregular surfaces.

In the past (Bishop, 1955), comparisons have been made between the Taylor method and the modified Bishop method (as originally developed) by examining the factor of safety as a function of the central angle of the assumed slip circle, θ, as shown in Figures 5a and 5b. Similar comparisons have also been made with regards to the more sophisticated analyses (Morgenstern and Price, 1965). The general conclusion is that the modified Bishop method gives a better approximation of the more rigorous analyses than the Taylor method (Morgenstern and Price, 1965), and that the Taylor method is in gross error for large central angles of arc (Bishop, 1955).

In Figure 6, a plot of Equation 25 (y_o, the moment center, versus F) is presented for two different slip circles, labelled 1 and 2. The soil



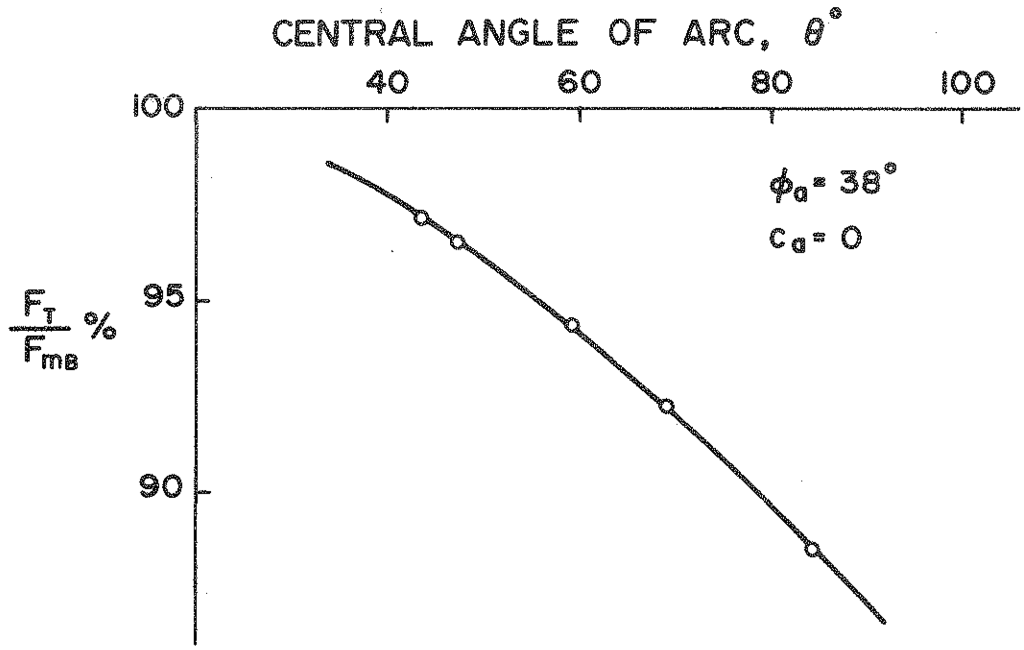


Figure 5 - Influence of Central Angle of Arc on Factor of Safety

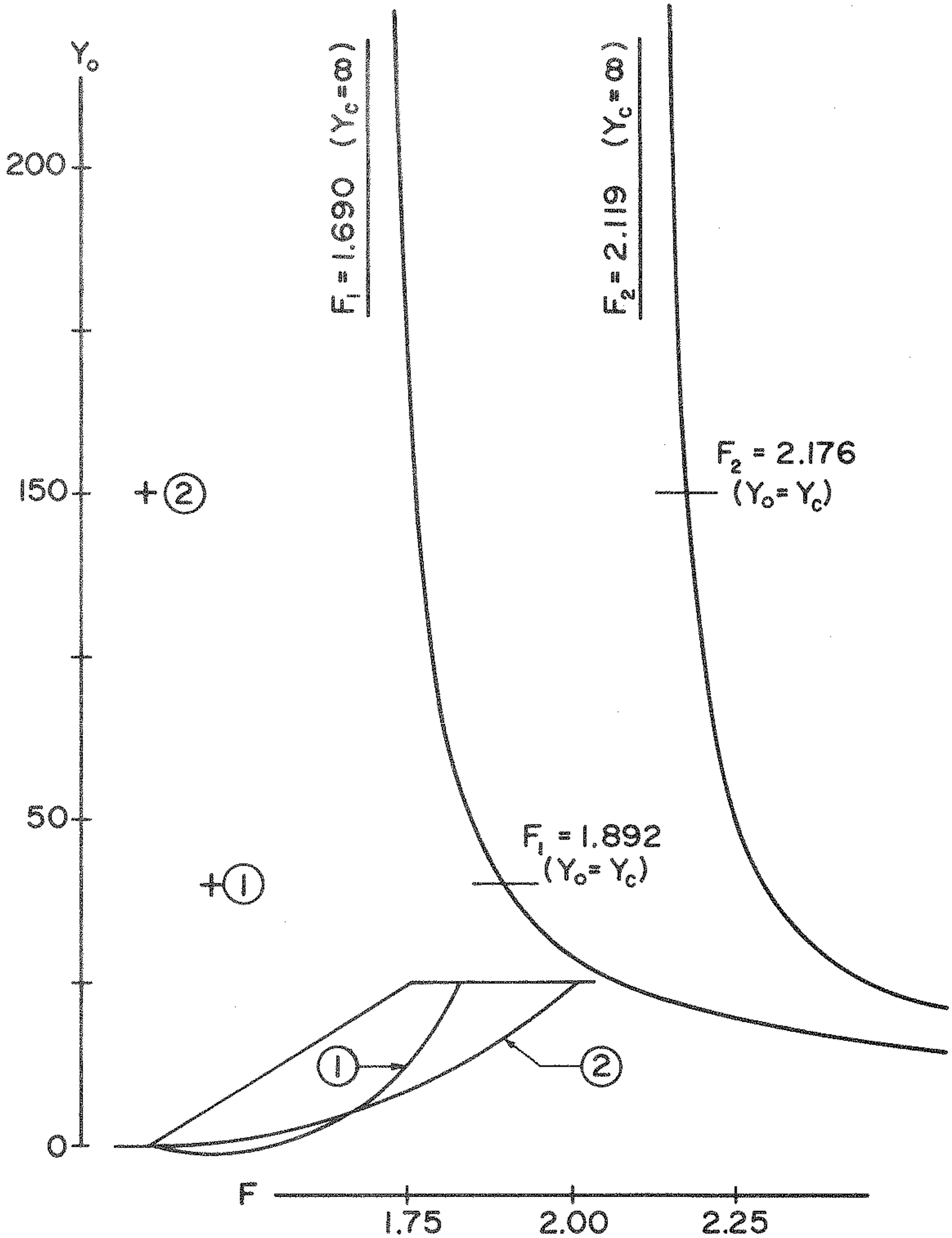


Figure 6 - Factor of Safety versus Moment Center for $\phi_a = 35^\circ$, $c_a = 90$ psf

profile and assumed slip circles are superimposed on the plot so that the vertical scale of the plot is conformable with the vertical and hroizontal scale of the profile.

Figures 7 and 8 show the results for the same profile and circles but with different material parameters.

Table 2 summarizes the Figures, includes the results of the Taylor analysis, and adds circles intermediate to 1 and 2.

The unique point that should be used for summation of external moments with the modified Bishop assumption is seen to be not the center of the circle but rather y_o = infinity. Examination of Table 2 indicates that the ratio of the Taylor result and the adapted, modified Bishop result (y_o = infinity) is essentially constant with the variation in θ. Since the modified Bishop ($y_o = y_c$) factor of safety varies with y_o (which is indirectly a function of θ), consistent comparisons when seeking the minimum factor of safety are not possible. Use of the modified Bishop assumption ($\Delta X = 0$) with summation of external moments at y_o = infinity seems more appropriate, because the F is a minimum with respect to such a center. The use of $y_o = y_c$ for the Taylor assumption is appropriate because of the force summation in the radial direction and because the F is minimized with such a center. The $y_o = \infty$ center is convenient also for the irregular surface analysis.

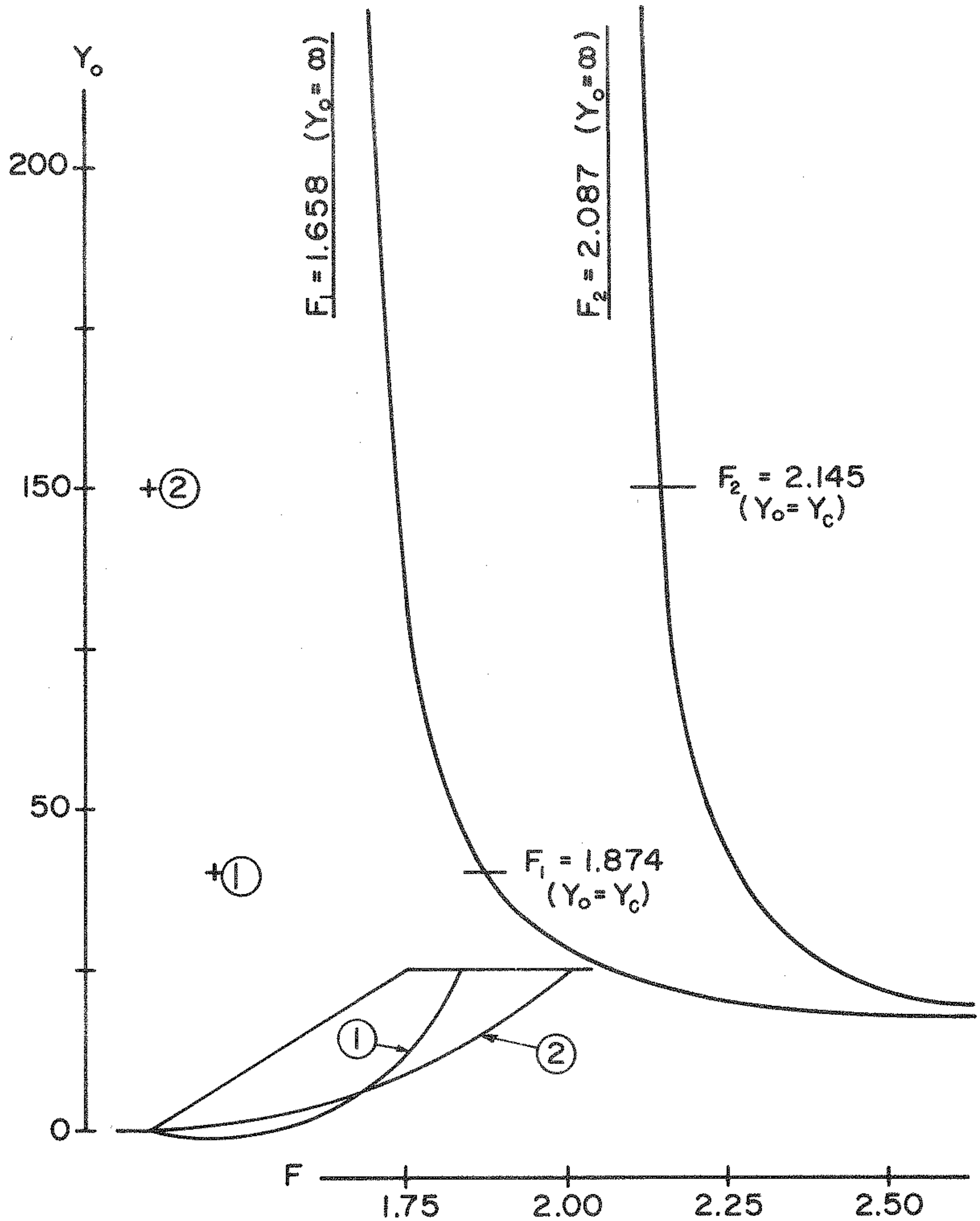


Figure 7 - Factor of Safety versus Moment Center for $\phi_a = 38°$

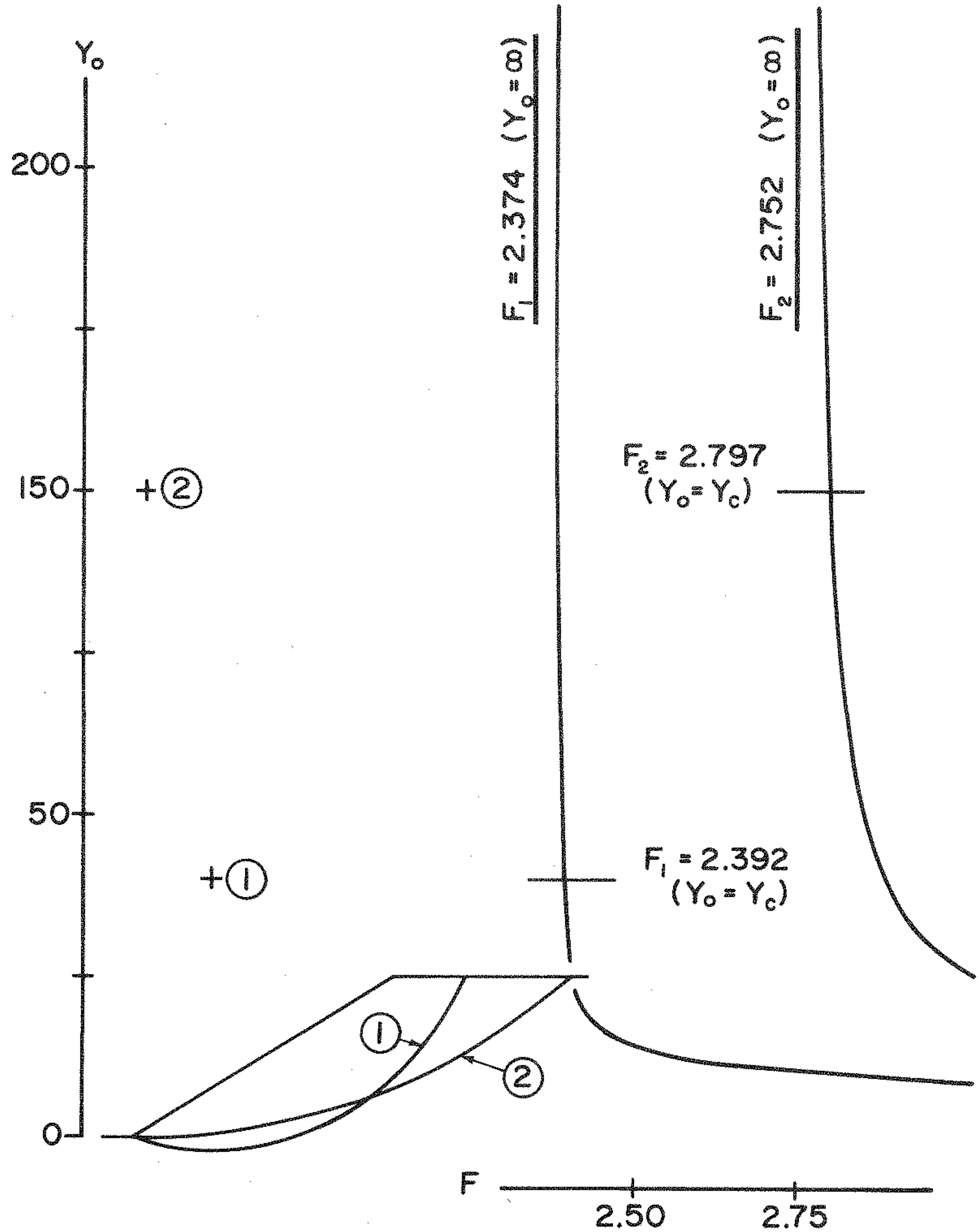


Figure 8 - Factor of Safety versus Moment Center for $c_a = 1000$ psf.

Table 2

Summary of Central Angle of Arc and Moment Center versus F

(γ = 130 pcf)

Central ∡ θ^o	$\phi_a = 35^o$, c_a = 90 pcf			$\phi_a = 38^o$			c_a = 1000 psf		
	F_T	F_{MB} $Y_o = Y_c$	F_{MB} $Y_o = \infty$	F_T	F_{MB} $Y_o = Y_c$	F_{MB} $Y_o = \infty$	F_T	F_{MB} $Y_o = Y_c$	F_{MB} $Y_o = \infty$
84.26 (circle 1)	1.704	1.892	1.690	1.661	1.874	1.658	2.392	2.392	2.374
68.53	1.764	1.891	1.756	1.726	1.870	1.726	2.407	2.407	2.362
58.20	1.849	1.944	1.843	1.816	1.927	1.817	2.456	2.456	2.413
51.55	1.941	2.016	1.936	1.910	1.995	1.911	2.537	2.537	2.496
47.08	2.032	2.095	2.028	2.001	2.071	2.002	2.650	2.650	2.609
44.04 (circle 2)	2.121	2.176	2.119	2.086	2.145	2.087	2.797	2.797	2.752

PROGRAM CHARACTERISTICS

Purpose

The Fortran IV programs developed under this research include five main programs and eleven, interchangeable, supporting routines. The four main programs used for stability analysis are designated SLOPE1, SLOPE2, SLOPE3, and SLOPE4. The first three programs, SLOPE1, SLOPE2, and SLOPE3, analyze circular failure surfaces and differ only in the definition of the factor of safety. SLOPE1 calculates the Taylor factor of safety (Equation 5), and SLOPE2 calculates the modified Bishop factor of safety (Equation 14). The third program, SLOPE3 uses in the stability analysis the adjusted form of the modified Bishop factor of safety, i.e., the moment center is equal to y_o = infinity (Equation 26). The fourth stability program, SLOPE4, also calculates the adjusted form of the modified Bishop factor of safety but for irregular shaped failure surfaces.

The fifth main program, FLWNET, is a supporting program for the stability package. It is required whenever a flow net is included in the analysis. Program FLWNET generates the twenty-one coefficients needed to define a fifth order polynomial trend surface.

Table 3 lists the supporting routines called by each of the five main programs.

Table 3

Supporting Routines of each

Main Program

SLOPE1	SLOPE2	SLOPE3	SLOPE4	FLWNET
INOUT	INOUT	INOUT	INOUT	HEAD
STORE1	STORE2	STORE3	STORE4	
CROSS	CROSS	CROSS	SLPBND	
WEIGHT	WEIGHT	WEIGHT	WEIGHT	
HEAD	HEAD	HEAD	HEAD	
RADIUS	RADIUS	RADIUS	FACTOR	
	FACTOR	FACTOR		

Usage

Input to the four stability programs is in three groups of information: description of the slope profile; description of the slip surface or search parameters; and transfer of control options.

Description of Profile

All four programs accept the same format for the description of the profile. The soil profile needs to be described completely in the first quadrant of a Cartesian coordinate system by a series of straight line segments. In addition, the x coordinate of the slope crest must be greater than the x coordinate of the slope toe, thereby describing the actual sloping ground surface by positive sloping line segments. The following order must be observed for entering the boundary segments. First, the ground surface segments are sequenced from left to right. Next, the subsurface boundary segments are ordered such that any vertical line would intersect, with depth, boundaries that are in a subsequent position of the order. This restriction on subsurface boundaries is necessitated by the slice weight calculation, but, of course, may be removed if execution time is not important and an ordering loop is provided in subroutine WEIGHT.

Correlation between the boundary segments of the profile and the soil types within the profile is achieved by recording with each boundary segment an integer code. The magnitude of this integer code represents the order in which the properties of the soil type below the segment are read later. A particular soil type, represented by γ, c', and ϕ', needs to be entered only once, whereas, it is quite likely that several boundary segments will have the same integer code.

Both concentrated and uniform loads acting on the ground surface can be accommodated.

An equilibrium condition of ground water (for either static or steady state flow) can be managed by either of two options. For both cases, it is necessary to describe the entire ground water surface by a series of coordinate points entered in increasing x coordinate order. One option accounts for pore pressures by letting the vertical distance from the point in question to the ground water surface equal the pressure head. The other option allows for flow net variations by using the polynomial trend surface determined by program FLWNET.

Description of Slip Surface-Search Parameters

The format of the second group of information, the description of the slip surface or search parameters, is the same for the first three programs, SLOPE1, SLOPE2, and SLOPE3. Specific circular failure surfaces can be analyzed by describing the radius and the (x,y) coordinates of the center for each circle. If, on the other hand, the minimum factor of safety of a profile is sought, a grid search must be conducted.

Under the grid search option, it is necessary to indicate not only the specifications for the size of the grid but also a radius increment value. For any given circle center, subroutine RADIUS generates an array of radii that includes the maximum of the toe radius and crest radius, and all radii of circles that are tangent to subsurface boundaries. The maximum value in the array is the minimum of radii of circles that are tangent to boundaries that have a zero soil type code. Therefore, it is imperative that the latter boundaries be entered accordingly. The main program calculates the factor of safety of all circles in the radius array. In addition, the main program generates circles having radii that are greater than each array radius, by integer increments of the radius increment value, but less than the succeeding array radius.

Figure 9 illustrates the grid search parameters.

Program SLOPE4 requires a different format for the description of the slip surface or search parameters than SLOPE1, SLOPE2, and SLOPE3. If a specific irregular surface needs to be analyzed, it must be described by a set of coordinates points ordered in increasing x coordinates. For the irregular surface analysis, it is also possible to conduct a search by defining eight parameters. The main program will generate surfaces within the irregular search specifications, overlay each surface on the soil profile, and solve for the factor of safety of each surface that is compatible with the profile.

If one were to assume that the critical irregular failure surface for the slope shown in Figure 10 passed through the points I_1 and I_2 where the y coordinate of I_1 is the minimum y coordinate of the surface, it would follow that the limiting shapes for the range of probable surfaces would be I_1I_2 and I_1AI_2. Recognizing that the critical failure surface will possess some continuity, it is necessary to scan the triangle I_1AI_2 in some sequential search scheme.

Leonardo of Pisa, a thirteenth century mathematician, did a great deal of work in connection with series, from which the

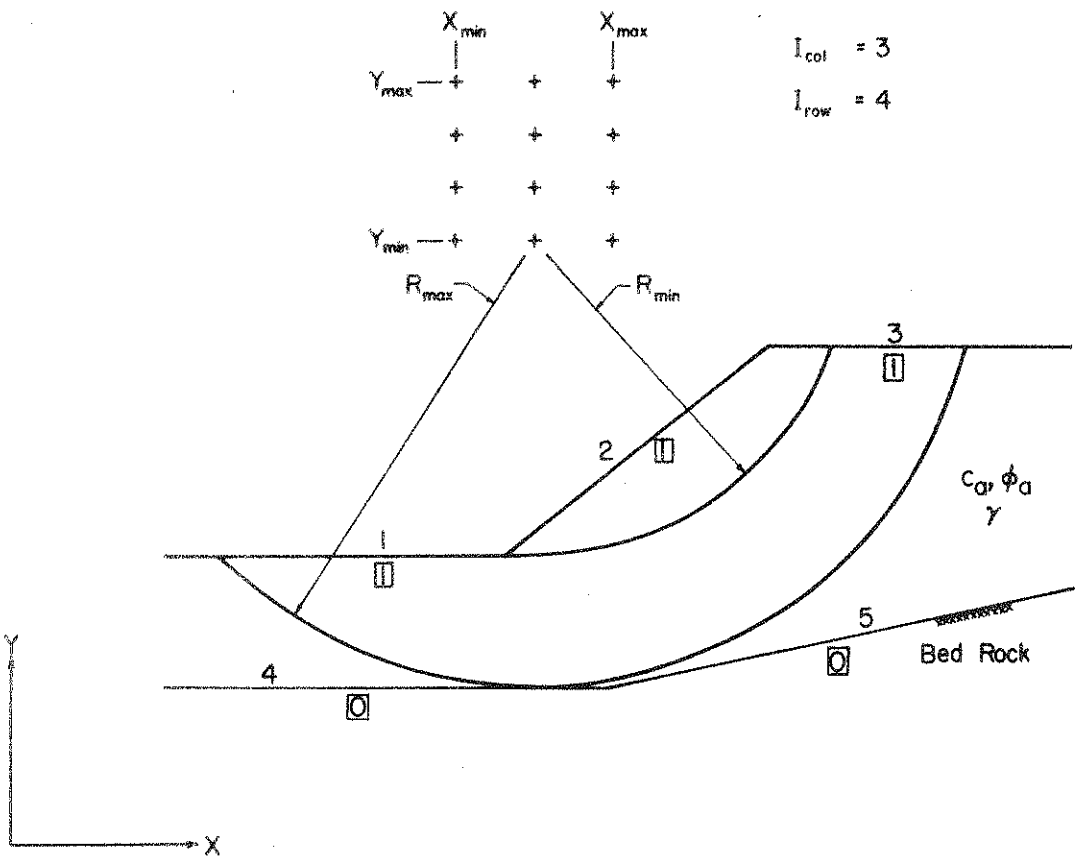


Figure 9 - Grid Search Parameters for Circular Surface Analysis

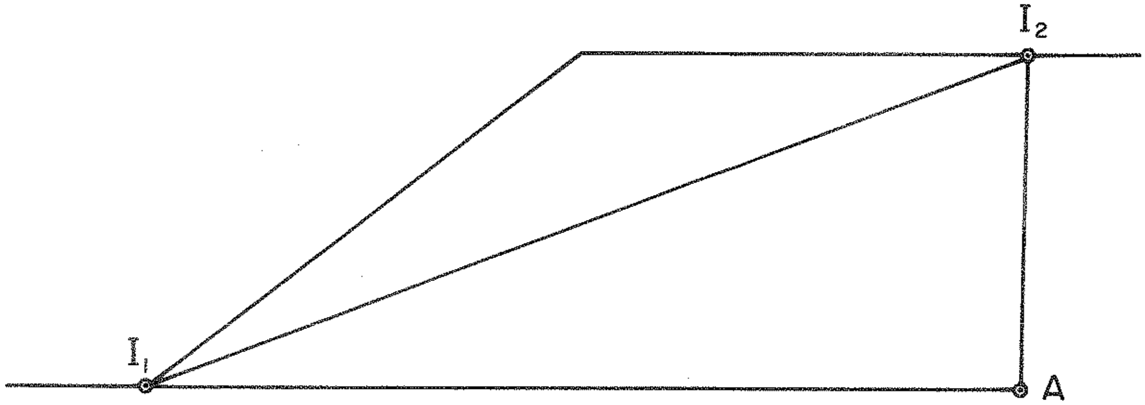


Figure 10 - Probable Range of Irregular Surfaces

Fibonacci sequence evolved (Wilde, 1964). This sequence is a progression in which the first two entries are defined as unity and all succeeding entries are equal to the sum of the two preceding entries. Or, in mathematical terms,

$$T_o = 1$$

$$T_1 = 1$$

$$T_k = T_{k-1} + T_{k-2} \qquad k = 2,3,\ldots \qquad 27$$

The Fibonacci sequence is used for generating probable irregular surfaces.

The eight variables needed for the search are: y_{max}, y_{min}, x_{max}, x_{min}, x-control, N_{min}, N_{max}, and N_{sur}. The main program first divides the distance ($y_{max} - y_{min}$) into N_{min} layers.[1] The array of y coordinates of the layers, Y*, is calculated by a cosine function.

$$y_k = y_o + H\,(1 - \cos\frac{\pi k}{2n}) \qquad k = 1,2,\ldots,n \qquad 28$$

where

$$H = y_{max} - y_{min}$$

$$y_o = y_{min}$$

and initially,

$$n = N_{min}$$

1. The program can be modified to read in the turning points. This would be particularly suited to profiles characterized by weak-layer stratification.

Using the Y* coordinates, a series of straight line segments is generated between x-control and x_{max} such that the slope of each succeeding segment is in Fibonacci multiples of the slope of the initial segment. The x coordinates of the segments constitute the X* array.

Therefore,

$$x_k = x_{k-1} + \frac{y_k - y_{k-1}}{\rho \, T_k} \qquad k = 1,2,\ldots,n \tag{29}$$

where

$$x_o = x - \text{control}$$

$$x_n = x_{max}$$

and

$$\rho = \frac{\sum_{i=0}^{n} \frac{y_{i+1} - y_i}{T_{i+1}}}{x_n - x_o}$$

Having generated the surface (X*,Y*), the program examines the profile. If the specifications of the search and the definition of the profile are compatible, the factor of safety is calculated. The program then decreases x_n and calculates a new surface, and so on, until x_{min} is reached. This iteration is repeated N_{sur} times.

Next, n is incremented by one, and the entire loop is repeated. The search is completed when n equals N_{max}.

When (x_o = x-control, $y_o = y_{min}$) is defined within the profile, each generated surface is completed by one additional segment directed back to the ground surface. For each (X*,Y*), the program currently calculates the factor of safety for three such segments, directed at 30°, 45°, and 60° from the-x direction.

Figure 11 illustrates the irregular surface search parameters, and Figure 12 demonstrates the variation in shape resulting from an increase in n with all other variables constant.

Transfer of Control

The third group of information, the transfer of control option, is also acceptable to all four stability programs. The transfer card allows for re-entry into either the first group or second group of information.

Flow Net Analysis

Input data for the fifth main program, FLWNET, should be conformable with the Cartesian coordinate system of the stability programs. In order to perform the trend surface analysis, it is necessary to know and record x, y, and total head observations. The accuracy of the fit is of course commensurate with the number of observations.

Special Computational Methods

Slice Width for Circular Analysis

In the method of slices, the factor of safety for a given circular failure surface converges to a constant as the number of slices is increased. This effect is a result of two factors. First, the length of the failure surface approaches in the limit the true arc length of the circle as the circle is divided into smaller secants.

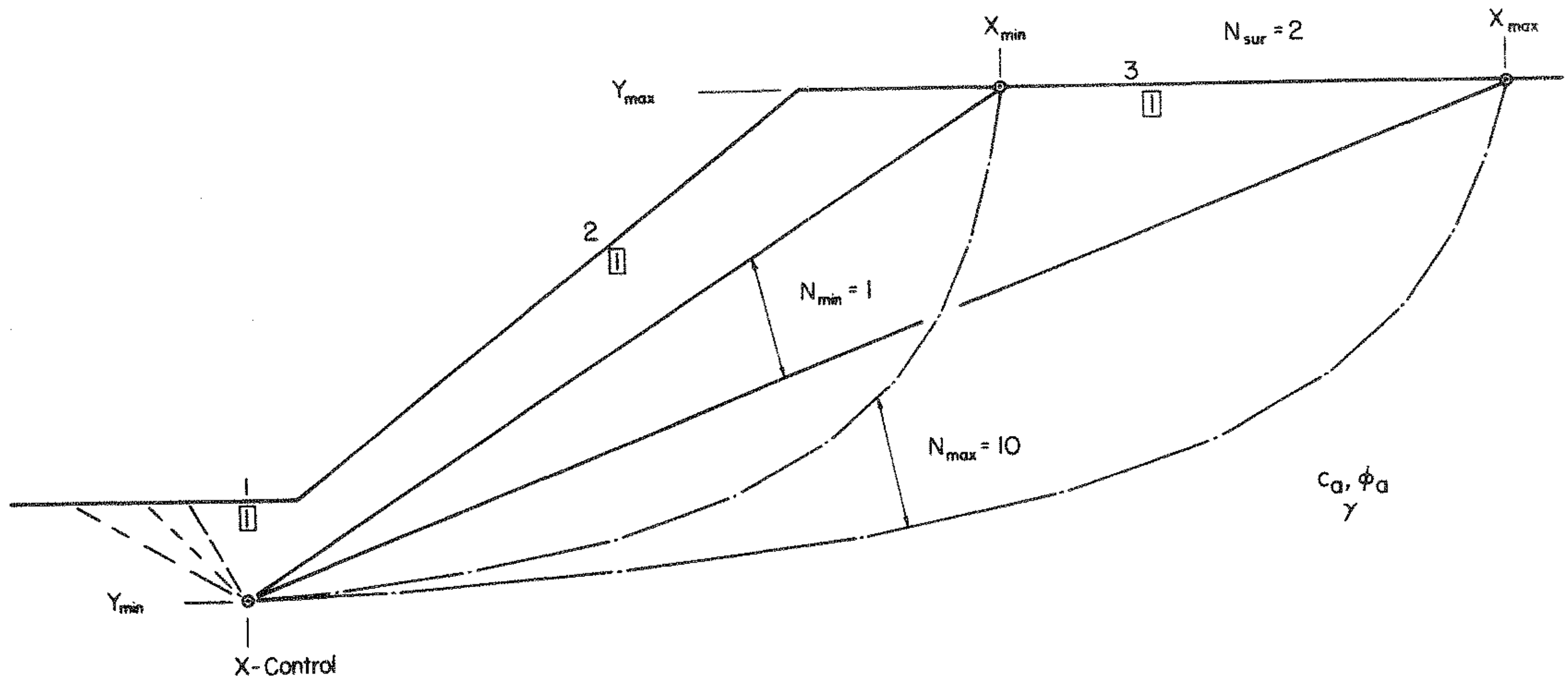


Figure 11 - Irregular Search Parameter for Irregular Surface Analysis

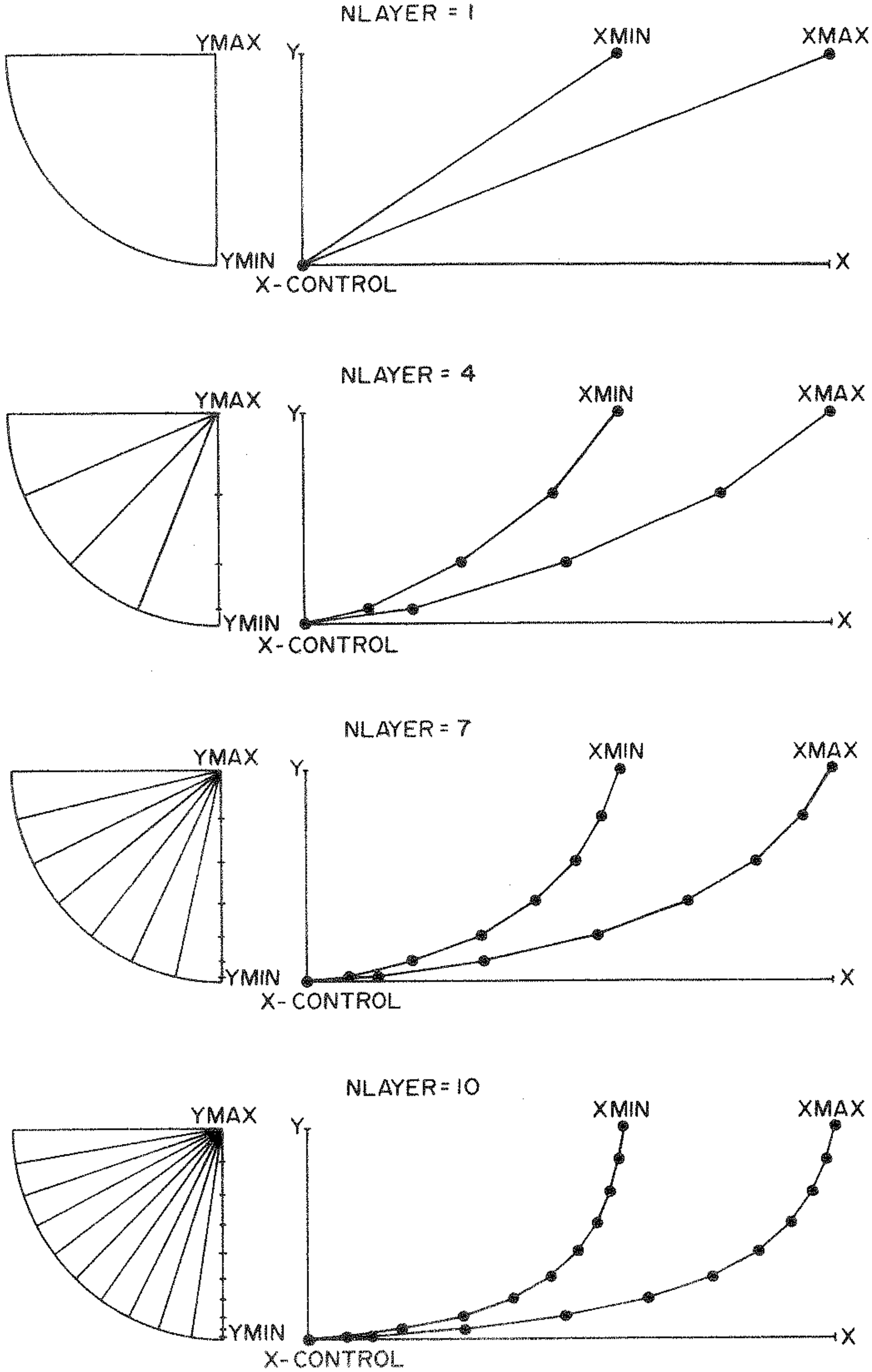


Figure 12 - Variation in Shape of Irregular Surface for Increasing n

The second factor, which is of lesser consequence, is that the weight of the subdivided failure mass approaches also in the limit the true weight of the sliding circular mass. In previous analyses, the sliding body has often been divided into n equal width slices, where n is an arbitrary value in the range of 10-25. However, it is more advantageous to allow the slice width to vary.

Referring to Figure 13, the error of approximating $\widehat{L}$ by $\overline{L}$ is related to θ, the central angle for the slice. By using a constant value of θ, rather than t, it is possible to minimize this error, thereby controlling the aforementioned effects, and giving a constant value for the factor of safety.

Again referring to Figure 13,

$$\overline{L} = 2R \sin \frac{\theta}{2} \qquad \text{from elementary geometry} \qquad 30$$

Also,

$$\cos \left(\frac{\theta}{2} + \eta\right) = \frac{t}{\overline{L}} \qquad 31$$

Substituting $\overline{L}$,

$$t = 2R \sin \frac{\theta}{2} \cos \left(\frac{\theta}{2} + \eta\right) \qquad 32$$

or

$$x_{i+1} = x_i + 2R \sin \frac{\theta}{2} \cos \left(\frac{\theta}{2} + \eta\right) \qquad 33$$

Since it is not possible to determine by analytical means a limiting value of θ, a number of trials were investigated. As a result, a value of θ = 0.1 radian was used in each program.

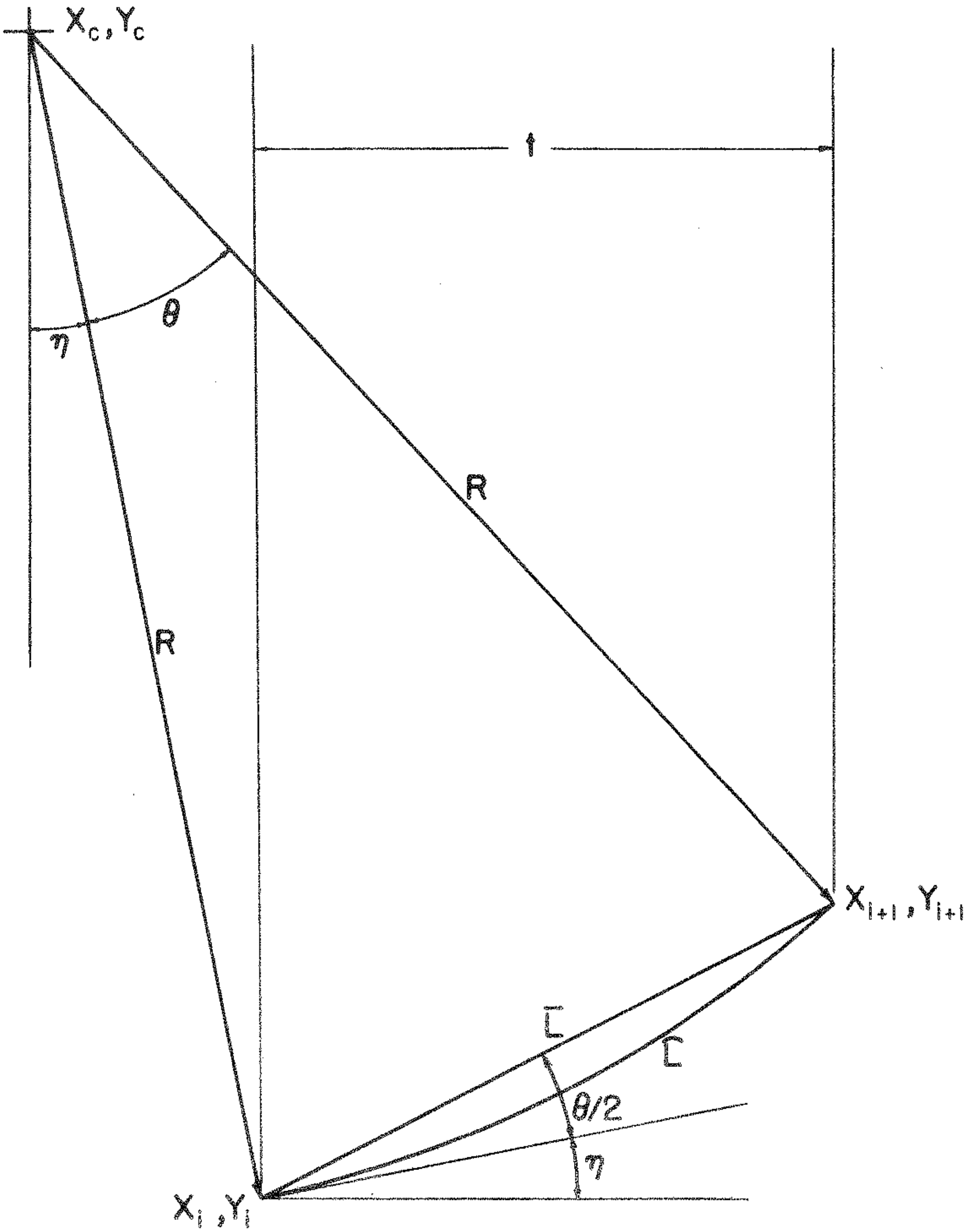


Figure 13 - Central Angle of Slice and Slice Width

Iteration for Factor of Safety

In the modified Bishop equation and in the adjusted form of the modified Bishop equation, the factor of safety cannot be solved for explicity. Consequently, an iterative technique is necessary.

In the Newton-Raphson method of finding zeros (Hamming, 1962), it is possible to show that a better solution of g(F) is given by,

$$F_1 = F_o - \frac{g(F_o)}{g'(F_o)} \tag{34}$$

where F_o is an approximate solution.

The modified Bishop equation as developed previously is

$$g(F) = \Sigma \bar{y} \left(\frac{A_1 - FA_2}{F + A_3}\right) = 0 \tag{35}$$

Taking the first derivative yields,

$$g'(F) = \Sigma \{\bar{y} [- \frac{A_1 - FA_2}{(F + A_3)^2} - \frac{A_2}{F + A_3}]\} \tag{36}$$

Simplifying,

$$g'(F) = - \Sigma \bar{y} [\frac{A_1 + A_2A_3}{(F + A_3)^2}] \tag{37}$$

Backsubstituting,

$$F_1 = F_o + \frac{\Sigma \bar{y} \left(\frac{A_1 - F_oA_2}{F_o + A_3}\right)}{\Sigma \bar{y} [\frac{A_1 + A_2A_3}{(F_o + A_3)^2}]} \tag{38}$$

Subroutine FACTOR allows for a maximum of ten iterations of Equation 38, although convergence to a successive difference of less than 0.005 generally occurs within the third iteration.

Trend Surface Analysis

Program FLWNET is a modification of program TREND developed by A. K. Turner (1969), for the GCARS system. The matrix algebra procedure used for the computation of the trend surface coefficients is described in Chapter 2 of Draper and Smith (1967).

Capacities and Limitations

The stability programs, as currently developed, are restricted by the size of the problem. Since linkage between the programs and routines is provided by blank common storage, it is imperative that for any change of dimension in one program a corresponding change be made in the other routines. To assist the user in making necessary changes, Table 4 is provided.

The maximum number of profile boundaries is twenty, with no more than fifteen different soil types allowed. The concentrated and uniform ground surface loadings are limited to five each. The ground water surface can be defined by a maximum of nine coordinates.

In defining an irregular surface for the individual surface analysis, no more than twelve points can be used. The irregular search is limited by a maximum of ten layers.

Program FLWNET accommodates one-hundred observations for the polynomial fit.

Since the CDC 6500 has a 60-byte word length, single precision calculations were used in program FLWNET. For systems using word lengths of smaller size, double precision must be used for the matrix calculations. Therefore, the following variables should be declared double precision: A, AM, BB, PAR, SSR, SSZ, and XINV.

Table 5 lists the CDC 6500 word length of each routine.

Table 5

CDC 6500 Program Lengths

Program Name	Program Length, Words (OCTAL)	
SLOPE1	2617	Including I-O Buffers
SLOPE2	2624	Including I-O Buffers
SLOPE3	2624	Including I-O Buffers
SLOPE4	3222	Including I-O Buffers
FLWNET	5353	Including I-O Buffers
INOUT	1154	Including I-O Buffers
STORE1	566	
STORE2	636	
STORE3	613	
STORE4	553	
CROSS	604	
SLPBND	400	
WEIGHT	214	
RADIUS	236	
FACTOR	124	
HEAD	112	

SUMMARY AND CONCLUSIONS

The primary objective of this research was the development of a computer-assisted system for the prediction of slope stability. The resulting set of programs is proficient in accommodating a complex ground surface and subsurface profile of spatial variations in material properties, a steady state flow domain, both uniform and concentrated ground surface loadings. Efficient search patterns are provided to assist the engineer in locating the critical shearing surface.

It has been contended (Bishop, 1955) that the modified Bishop method gives a more realistic solution, within the congruence of limiting equilibrium, than the Taylor method. The argument that the Bishop assumption ($\Delta X = 0$) better approximates the real situation than the Taylor assumption ($\Delta E_n + \Delta X_n = 0$) seems to have merit. However, neither method satisfies equilibrium and the factor of safety, F, as calculated by the modified Bishop has been shown to vary in a regular fashion with the center selected for the moment equation. If the use of the circle center as a center for moments gives a more realistic value for F, it is believed to be a matter of coincidence. Accordingly it is recommended that this element of chance be eliminated by taking the moment center at a very large value of the Y coordinate, rather than at the center of the assumed circular failure surface. Use of the center at a large value of Y further produces a minimum value of F. Although the Taylor method is applicable only to circular failure surfaces, the adjusted form of the modified Bishop approach can be applied to the irregular surface as well.

More sophisticated methods of analysis than the Taylor or modified Bishop techniques exist, but, for most practical problems, the simpler methods are satisfactory. It is important not only to use a meaningful method of analysis in determining stability, but also to thoroughly, yet efficiently, scan the soil profile for features that will tend to yield the minimum value of F. This latter requirement emphasizes the need for a rapid method of analysis. Therefore, the more sophisticated methods of analysis should probably serve as a means of assessing the reliability of the simpler methods for special problems, rather than being used in the search proper.

RECOMMENDATIONS FOR FURTHER STUDY

1. It would be desirable to compare the results of the more sophisticated methods of analysis, e.g., the Morgenstern-Price and the Bell method, with the results of the adapted form of the modified Bishop method. It may be feasible to pick a particular point for external moment summation in the simpler method, determined by the characteristic shape of Equation 25, in predicting a value of F approximately equal to that of the more sophisticated methods.

2. The irregular search technique needs further development. At present, the surface from (x-control, x_{min}) is generated in the negative X direction by one of three straight lines. It would be desirable to expand the internal search to include this segment in the determination of a minimum F.

3. The present program does not accommodate pore pressures in excess of a steady state equilibrium. Such pressures are extant during undrained or partially drained shear. Analysis of the ordinary draw-down case requires such input.

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LIST OF REFERENCES

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APPENDIX A

PROGRAM LISTING AND DOCUMENTATION

APPENDIX A

PROGRAM LISTING AND DOCUMENTATION

Purdue University has implemented a documentation routine titled FORSTAT. Program FORSTAT lists a given routine and produces a cross-reference listing for both statement and variable references. This entire program package has been listed by FORSTAT as an aid to the user in making modifications.

FORSTAT Listing of Program SLOPE1

```
1.          PROGRAM SLOPE1(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)            SL1    2
       C    -----------------------------------------------------------------SL1    4
       C                              PROGRAM SLOPE1                         SL1    6
       C    -----------------------------------------------------------------SL1    8
       C    PURPOSE-                                                         SL1   10
       C         TO ANALYZE A SLOPE PROFILE FOR A CIRCULAR TYPE OF FAILURE   SL1   12
       C    USING THE TAYLOR FACTOR OF SAFETY.                               SL1   14
       C    -----------------------------------------------------------------SL1   16
       C    CONTROL CARDS-                                                   SL1   18
       C                                                                     SL1   20
       C    ALL FORMATS ARE INTEGER OR FIXED POINT DEPENDING UPON FORTRAN    SL1   22
       C    CODING OF VARIABLES, UNLESS OTHERWISE STATED.                    SL1   24
       C    INPUT MUST BE IN THE FOLLOWING UNITS,                            SL1   26
       C         LENGTH IN FEET.                                             SL1   28
       C         FORCE IN POUNDS,                                            SL1   30
       C         ANGLE IN DEGREES.                                           SL1   32
       C                                                                     SL1   34
       C    (A) DESCRIPTION OF PROFILE-                                      SL1   36
       C              SEE SUBROUTINE  INOUT.                                 SL1   38
       C                                                                     SL1   40
       C    (B) DESCRIPTION OF SLIP SURFACE/SEARCH-                          SL1   42
       C         (1) OPTION CARD                                             SL1   44
       C              IOPT  (COL 1) IF IOPT=1, INDIVIDUAL CIRCLE ANALYSIS.   SL1   46
       C                            IF IOPT=2, GRID ANALYSIS.                SL1   48
       C              INUM  (COL 2-3) NUMBER OF CIRCLES TO BE READ OR NUMBER OF SL1 50
       C                              GRIDS TO BE READ DEPENDING UPON IOPT.  SL1   52
       C                                                                     SL1   54
       C         (2) SLIP SURFACE/SEARCH PARAMETER CARD(S)                   SL1   56
       C                                                                     SL1   58
       C    COMPLETE EITHER 2A OR 2B DEPENDING UPON THE IOPT VALUE.  THERE MUST SL1 60
       C    BE INUM TOTAL CARDS IN EITHER CASE.                              SL1   62
       C                                                                     SL1   64
       C              (2A) INDIVIDUAL CIRCLE ANALYSIS CARD                   SL1   66
       C                   XCEN (COL 1-10)  X-CENTER OF CIRCLE.              SL1   68
       C                   YCEN (COL 11-20) Y-CENTER OF CIRCLE.              SL1   70
       C                   R    (COL 21-30) RADIUS OF CIRCLE.                SL1   72
       C                                                                     SL1   74
       C              (2B) GRID ANALYSIS CARD                                SL1   76
       C                   XMAX (COL 1-10)  MAXIMUM X-COORD OF GRID.         SL1   78
       C                   XMIN (COL 11-20) MINIMUM X-COORD OF GRID.         SL1   80
       C                   YMAX (COL 21-30) MAXIMUM Y-COORD OF GRID.         SL1   82
       C                   YMIN (COL 31-40) MINIMUM Y-COORD OF GRID.         SL1   84
       C                   DRAD (COL 41-50) RADIUS INCREMENT VALUE.          SL1   86
       C                   ICOL (COL 51-52) NUMBER OF COLUMNS IN GRID.       SL1   88
       C                   IROW (COL 53-54) NUMBER OF ROWS IN GRID.          SL1   90
       C                                                                     SL1   92
       C    (C) TRANSFER OF CONTROL-                                         SL1   94
       C         (1) CONTROL OPTION CARD                                     SL1   96
       C              WAY  (COL 1-3) IF WAY=NEW, CONTROL IS TRANSFERRED TO (A). SL1 98
       C                             IF WAY=OLD, CONTROL IS TRANSFERRED TO (B). SL1 100
       C                             IF WAY=END, PROGRAM IS TERMINATED.      SL1  102
       C                                                                     SL1  104
       C    -----------------------------------------------------------------SL1  106
       C    REQUIRED ROUTINES-                                               SL1  108
       C         SUBROUTINE STORE1                                           SL1  110
       C         SUBROUTINE INOUT                                            SL1  112
       C         SUBROUTINE CROSS                                            SL1  114
       C         SUBROUTINE RADIUS                                           SL1  116
       C         SUBROUTINE WEIGHT         (CALLED BY STORE1)                SL1  118
       C         FUNCTION HEAD             (CALLED BY STORE1)                SL1  120
       C    -----------------------------------------------------------------SL1  122
       C    SYSTEM ROUTINES-                                                 SL1  124
       C         FUNCTION FLOAT                                              SL1  126
       C    -----------------------------------------------------------------SL1  128
2.          INTEGER OLD,WAY                                                  SL1  130
3.          DIMENSION RAD(15)                                                SL1  132
4.          DATA NEW,OLD/3HNEW,3HOLD/                                        SL1  134
5.     5    CALL INOUT (1)                                                   SL1  136
6.     10   READ (5,130) IOPT,INUM                                           SL1  138
7.          GO TO (15,30), IOPT                                              SL1  140
       C    ------------------------------------                             SL1  142
       C    INDIVIDUAL CIRCLE OPTION                                         SL1  144
       C    ------------------------------------                             SL1  146
8.     15   WRITE (6,135) INUM                                               SL1  148
9.          WRITE (6,140)                                                    SL1  150
```

```
      DO 25 K=1,INUM
         READ (5,145) XCEN,YCEN,R
         ISTOP=1
         CALL CROSS (ISTOP,XCEN,YCEN,R)
         GO TO (20,25), ISTOP
   20    CALL STORE1 (XCEN,YCEN,R,FT)
         WRITE (6,150) XCEN,YCEN,R,FT
   25 CONTINUE
      GO TO 115
C
C    ----------------------------------
C     GRID OPTION
C    ----------------------------------
   30 WRITE (6,155) INUM
      DO 110 K=1,INUM
         READ (5,175) XMAX,XMIN,YMAX,YMIN,DRAD,ICOL,IROW
         WRITE (6,170) XMAX,YMAX,XMIN,YMIN,ICOL,IROW,DRAD
         WRITE (6,140)
         DX=FLOAT(ICOL-1)
         IF (DX) 35,35,40
   35    DX=1.0
         GO TO 45
C
   40    DX=(XMAX-XMIN)/DX
   45    DY=FLOAT(IROW-1)
         IF (DY) 50,50,55
   50    DY=1.0
         GO TO 60
C
   55    DY=(YMAX-YMIN)/DY
   60    DO 105 IY=1,IROW
            YCEN=YMAX-FLOAT(IY-1)*DY
            DO 100 IX=1,ICOL
               FMIN=999999.
               XCEN=XMIN+FLOAT(IX-1)*DX
               WRITE (6,160) XCEN,YCEN
               CALL RADIUS (XCEN,YCEN,RAD,NRAD)
               DO 95 I=1,NRAD
                  R=RAD(I)
   65             ISTOP=1
                  CALL CROSS (ISTOP,XCEN,YCEN,R)
                  GO TO (70,85), ISTOP
   70             CALL STORE1 (XCEN,YCEN,R,FT)
                  IF (FT-FMIN) 75,80,80
   75             FMIN=FT
   80             WRITE (6,165) R,FT
   85             IF (I-NRAD) 90,95,95
   90             R=R+DRAD
                  IF (R-RAD(I+1)) 65,95,95
   95          CONTINUE
  100       WRITE (6,185) FMIN
  105    WRITE (6,180)
  110 CONTINUE
C    ----------------------------------
C     DETERMINE TRANSFER OF CONTROL
C    ----------------------------------
  115 READ (5,190) WAY
      IF (WAY-NEW) 120,5,120
  120 IF (WAY-OLD) 125,10,125
  125 STOP
C
  130 FORMAT (I1,I2)
  135 FORMAT (1H1///4X,*INDIVIDUAL CIRCLE OPTION SPECIFIED*/13X,I3,* CIRS
     1CLES TO BE ANALYZED*//)
  140 FORMAT (1H /8X,*X-CENTER*,5X,*Y-CENTER*,5X,*RADIUS*,10X,*FS*//)
  145 FORMAT (3F10.4)
  150 FORMAT (1H 6X,F8.1,5X,F8.1,4X,F8.2,F15.3)
  155 FORMAT (1H1///4X,*GRID OPTION SPECIFIED*/13X,I3,* GRIDS TO BE ANAL
     1YZED*//)
  160 FORMAT (1H /8X,F8.1,5X,F8.1)
  165 FORMAT (1H 32X,F8.2,F13.3)
  170 FORMAT (1H ////10X,*GRID SPECIFICATIONS*//12X,*XMAX =*,F10.1,10X,*
     1YMAX =*,F10.1/12X,*XMIN =*,F10.1,10X,*YMIN =*,F10.1/12X,*ICOL =*,I
     210,10X,*IROW =*,I10//12X,*RADIUS INCREMENT =*,F10.1/)
  175 FORMAT (5F10.0,2I2)
  180 FORMAT (1H //)
  185 FORMAT (1H 14X,*MINIMUM FS FOR THIS CENTER = *,F10.3)
  190 FORMAT (A3)
      END
```

STATEMENT NUMBER	DEFINITION		REFERENCES		
5	5.		58.		
10	6.		59.		
15	8.		7.		
20	15.		14.		
25	17.		10.	14.	
30	19.		7.		
35	26.		25.		
40	28.		25.		
45	29.		27.		
50	31.		30.		
55	33.		30.		
60	34.		32.		
65	43.		52.		
70	46.		45.		
75	48.		47.		
80	49.		47.		
85	50.		45.		
90	51.		50.		
95	53.		41.	50.	52.
100	54.		36.		
105	55.		34.		
110	56.		20.		
115	57.		18.		
120	59.		58.		
125	60.		59.		
130	61.	FORMAT	6.		
135	62.	FORMAT	8.		
140	63.	FORMAT	9.	23.	
145	64.	FORMAT	11.		
150	65.	FORMAT	16.		
155	66.	FORMAT	19.		
160	67.	FORMAT	39.		
165	68.	FORMAT	49.		
170	69.	FORMAT	22.		
175	70.	FORMAT	21.		
180	71.	FORMAT	55.		
185	72.	FORMAT	54.		
190	73.	FORMAT	57.		

LABEL	TYPE	DEFINITION		REFERENCES								
CROSS	R	13.	SUBROUTINE	44.								
DRAD	R	21.		22.	51.							
DX	R	24.		25.	26.	28.	38.					
DY	R	29.		30.	31.	33.	35.					
FLOAT	R	24.	FUNCTION	29.	35.	38.						
FMIN	R	37.		47.	48.	54.						
FT	R	15.		16.	46.	47.	48.	49.				
I	I	41.		42.	50.	52.						
ICOL	I	21.		22.	24.	36.						
INOUT	I	5.	SUBROUTINE									
INUM	I	6.		8.	10.	19.	20.					
IOPT	I	6.		7.								
IROW	I	21.		22.	29.	34.						
ISTOP	I	12.		13.	14.	43.	44.	45.				
IX	I	36.		38.								
IY	I	34.		35.								
K	I	10.		20.								
NEW	I	4.	DATA	58.								
NRAD	I	40.		41.	50.							
OLD	I	2.	DATA	4.	59.							
R	R	11.		13.	15.	16.	42.	44.	46.	49.	51.	52.
RAD	R	3.		40.	42.	52.						
RADIUS	R	40.	SUBROUTINE									
STORE1	R	15.	SUBROUTINE	46.								
WAY	I	2.		57.	58.	59.						
XCEN	R	11.		13.	15.	16.	38.	39.	40.	44.	46.	
XMAX	R	21.		22.	28.							
XMIN	R	21.		22.	28.	38.						
YCEN	R	11.		13.	15.	16.	35.	39.	40.	44.	46.	
YMAX	R	21.		22.	33.	35.						
YMIN	R	21.		22.	33.							

FORSTAT Listing of Program SLOPE2

```
1.        PROGRAM SLOPE2(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      C ------------------------------------------------------------------
      C                           PROGRAM SLOPE2
      C ------------------------------------------------------------------
      C PURPOSE-
      C      TO ANALYZE A SLOPE PROFILE FOR A CIRCULAR TYPE OF FAILURE
      C USING THE MODIFIED BISHOP FACTOR OF SAFETY.
      C ------------------------------------------------------------------
      C CONTROL CARDS-
      C
      C ALL FORMATS ARE INTEGER OR FIXED POINT DEPENDING UPON FORTRAN
      C CODING OF VARIABLES, UNLESS OTHERWISE STATED.
      C INPUT MUST BE IN THE FOLLOWING UNITS,
      C      LENGTH IN FEET.
      C      FORCE IN POUNDS.
      C      ANGLE IN DEGREES.
      C
      C (A) DESCRIPTION OF PROFILE-
      C           SEE SUBROUTINE  INOUT.
      C
      C (B) DESCRIPTION OF SLIP SURFACE/SEARCH-
      C      (1) OPTION CARD
      C           IOPT  (COL 1) IF IOPT=1, INDIVIDUAL CIRCLE ANALYSIS.
      C                         IF IOPT=2, GRID ANALYSIS.
      C           INUM  (COL 2-3) NUMBER OF CIRCLES TO BE READ OR NUMBER OF
      C                           GRIDS TO BE READ DEPENDING UPON IOPT.
      C
      C      (2) SLIP SURFACE/SEARCH PARAMETER CARD(S)
      C
      C COMPLETE EITHER 2A OR 2B DEPENDING UPON THE IOPT VALUE.  THERE MUST
      C BE INUM TOTAL CARDS IN EITHER CASE.
      C
      C           (2A) INDIVIDUAL CIRCLE ANALYSIS CARD
      C                XCEN (COL 1-10)  X-CENTER OF CIRCLE.
      C                YCEN (COL 11-20) Y-CENTER OF CIRCLE.
      C                R    (COL 21-30) RADIUS OF CIRCLE.
      C
      C           (2B) GRID ANALYSIS CARD
      C                XMAX (COL 1-10)  MAXIMUM X-COORD OF GRID.
      C                XMIN (COL 11-20) MINIMUM X-COORD OF GRID.
      C                YMAX (COL 21-30) MAXIMUM Y-COORD OF GRID.
      C                YMIN (COL 31-40) MINIMUM Y-COORD OF GRID.
      C                DRAD (COL 41-50) RADIUS INCREMENT VALUE.
      C                ICOL (COL 51-52) NUMBER OF COLUMNS IN GRID.
      C                IROW (COL 53-54) NUMBER OF ROWS IN GRID.
      C
      C (C) TRANSFER OF CONTROL-
      C      (1) CONTROL OPTION CARD
      C           WAY  (COL 1-3) IF WAY=NEW, CONTROL IS TRANSFERRED TO (A).
      C                          IF WAY=OLD, CONTROL IS TRANSFERRED TO (B).
      C                          IF WAY=END, PROGRAM IS TERMINATED.
      C
      C ------------------------------------------------------------------
      C REQUIRED ROUTINES-
      C      SUBROUTINE STORE2
      C      SUBROUTINE INOUT
      C      SUBROUTINE CROSS
      C      SUBROUTINE RADIUS
      C      SUBROUTINE FACTOR
      C      SUBROUTINE WEIGHT         (CALLED BY STORE2)
      C      FUNCTION HEAD             (CALLED BY STORE2)
      C ------------------------------------------------------------------
      C SYSTEM ROUTINES-
      C      FUNCTION FLOAT
      C ------------------------------------------------------------------
2.        INTEGER OLD,WAY
3.        DIMENSION RAD(15)
4.        DATA NEW,OLD/3HNEW,3HOLD/
5.    5   CALL INOUT (2)
6.    10  READ (5,130) IOPT,INUM
7.        GO TO (15,30), IOPT
      C --------------------------------
      C INDIVIDUAL CIRCLE OPTION
      C --------------------------------
8.    15  WRITE (6,135) INUM
9.        WRITE (6,140)
```

```
          DO 25 K=1,INUM                                                SL2 154
             READ (5,145) XCEN,YCEN,R                                   SL2 156
             ISTOP=1                                                    SL2 158
             CALL CROSS (ISTOP,XCEN,YCEN,R)                             SL2 160
             GO TO (20,25), ISTOP                                       SL2 162
   20        CALL STORE2 (XCEN,YCEN,R,NSLICE)                           SL2 164
             CALL FACTOR (NSLICE,FB)                                    SL2 166
             WRITE (6,150) XCEN,YCEN,R,FB                               SL2 168
   25     CONTINUE                                                      SL2 170
          GO TO 115                                                     SL2 172
C                                                                       SL2 174
C     -----------------------------------                               SL2 176
C     GRID OPTION                                                       SL2 178
C     -----------------------------------                               SL2 180
   30     WRITE (6,155) INUM                                            SL2 182
          DO 110 K=1,INUM                                               SL2 184
             READ (5,160) XMAX,XMIN,YMAX,YMIN,DRAD,ICOL,IROW            SL2 186
             WRITE (6,165) XMAX,YMAX,XMIN,YMIN,ICOL,IROW,DRAD           SL2 188
             WRITE (6,140)                                              SL2 190
             DX=FLOAT(ICOL-1)                                           SL2 192
             IF (DX) 35,35,40                                           SL2 194
   35        DX=1.0                                                     SL2 196
             GO TO 45                                                   SL2 198
C                                                                       SL2 200
   40        DX=(XMAX-XMIN)/DX                                          SL2 202
   45        DY=FLOAT(IROW-1)                                           SL2 204
             IF (DY) 50,50,55                                           SL2 206
   50        DY=1.0                                                     SL2 208
             GO TO 60                                                   SL2 210
C                                                                       SL2 212
   55        DY=(YMAX-YMIN)/DY                                          SL2 214
   60        DO 105 IY=1,IROW                                           SL2 216
                YCEN=YMAX-FLOAT(IY-1)*DY                                SL2 218
                DO 100 IX=1,ICOL                                        SL2 220
                   FMIN=999999.                                         SL2 222
                   XCEN=XMIN+FLOAT(IX-1)*DX                             SL2 224
                   WRITE (6,170) XCEN,YCEN                              SL2 226
                   CALL RADIUS (XCEN,YCEN,RAD,NRAD)                     SL2 228
                   DO 95 I=1,NRAD                                       SL2 230
                      R=RAD(I)                                          SL2 232
   65                 ISTOP=1                                           SL2 234
                      CALL CROSS (ISTOP,XCEN,YCEN,R)                    SL2 236
                      GO TO (70,85), ISTOP                              SL2 238
   70                 CALL STORE2 (XCEN,YCEN,R,NSLICE)                  SL2 240
                      CALL FACTOR (NSLICE,FB)                           SL2 242
                      IF (FB-FMIN) 75,80,80                             SL2 244
   75                 FMIN=FB                                           SL2 246
   80                 WRITE (6,175) R,FB                                SL2 248
   85                 IF (I-NRAD) 90,95,95                              SL2 250
   90                 R=R+DRAD                                          SL2 252
                      IF (R-RAD(I+1)) 65,95,95                          SL2 254
   95              CONTINUE                                             SL2 256
  100           WRITE (6,185) FMIN                                      SL2 258
  105        WRITE (6,180)                                              SL2 260
  110     CONTINUE                                                      SL2 262
C     -----------------------------------                               SL2 264
C     DETERMINE TRANSFER OF CONTROL                                     SL2 266
C     -----------------------------------                               SL2 268
  115     READ (5,190) WAY                                              SL2 270
          IF (WAY-NEW) 120,5,120                                        SL2 272
  120     IF (WAY-OLD) 125,10,125                                       SL2 274
  125     STOP                                                          SL2 276
C                                                                       SL2 278
  130     FORMAT (I1,I2)                                                SL2 280
  135     FORMAT (1H1///4X,≠INDIVIDUAL CIRCLE OPTION SPECIFIED≠/13X,I3,≠ CIRSL2 282
         1CLES TO BE ANALYZED≠//)                                       SL2 284
  140     FORMAT (1H /8X,≠X-CENTER≠,5X,≠Y-CENTER≠,5X,≠RADIUS≠,10X,≠FS≠//)  SL2 286
  145     FORMAT (3F10.4)                                               SL2 288
  150     FORMAT (1H 6X,F8.1,5X,F8.1,4X,F8.2,F15.3)                     SL2 290
  155     FORMAT (1H1///4X,≠GRID OPTION SPECIFIED≠/13X,I3,≠ GRIDS TO BE ANALSL2 292
         1YZED≠//)                                                      SL2 294
  160     FORMAT (5F10.0,2I2)                                           SL2 296
  165     FORMAT (1H ////10X,≠GRID SPECIFICATIONS≠//12X,≠XMAX =≠,F10.1,10X,≠SL2 298
         1YMAX =≠,F10.1/12X,≠XMIN =≠,F10.1,10X,≠YMIN =≠,F10.1/12X,≠ICOL =≠,ISL2 300
         210,10X,≠IROW =≠,I10//12X,≠RADIUS INCREMENT =≠,F10.1/)         SL2 302
  170     FORMAT (1H /8X,F8.1,5X,F8.1)                                  SL2 304
  175     FORMAT (1H 32X,F8.2,F13.3)                                    SL2 306
  180     FORMAT (1H //)                                                SL2 308
  185     FORMAT (1H 14X,≠MINIMUM FS FOR THIS CENTER = ≠,F10.3)         SL2 310
  190     FORMAT (A3)                                                   SL2 312
          END                                                           SL2 314
```

STATEMENT NUMBER	DEFINITION		REFERENCES		
5	5.		60.		
10	6.		61.		
15	8.		7.		
20	15.		14.		
25	18.		10.	14.	
30	20.		7.		
35	27.		26.		
40	29.		26.		
45	30.		28.		
50	32.		31.		
55	34.		31.		
60	35.		33.		
65	44.		54.		
70	47.		46.		
75	50.		49.		
80	51.		49.		
85	52.		46.		
90	53.		52.		
95	55.		42.	52.	54.
100	56.		37.		
105	57.		35.		
110	58.		21.		
115	59.		19.		
120	61.		60.		
125	62.		61.		
130	63.	FORMAT	6.		
135	64.	FORMAT	8.		
140	65.	FORMAT	9.	24.	
145	66.	FORMAT	11.		
150	67.	FORMAT	17.		
155	68.	FORMAT	20.		
160	69.	FORMAT	22.		
165	70.	FORMAT	23.		
170	71.	FORMAT	40.		
175	72.	FORMAT	51.		
180	73.	FORMAT	57.		
185	74.	FORMAT	56.		
190	75.	FORMAT	59.		

LABEL	TYPE	DEFINITION		REFERENCES								
CROSS	R	13.	SUBROUTINE	45.								
DRAD	R	22.		23.	53.							
DX	R	25.		26.	27.	29.	39.					
DY	R	30.		31.	32.	34.	36.					
FACTOR	R	16.	SUBROUTINE	48.								
FB	R	16.		17.	48.	49.	50.	51.				
FLOAT	R	25.	FUNCTION	30.	36.	39.						
FMIN	R	38.		49.	50.	56.						
I	I	42.		43.	52.	54.						
ICOL	I	22.		23.	25.	37.						
INOUT	I	5.	SUBROUTINE									
INUM	I	6.		8.	10.	20.	21.					
IOPT	I	6.		7.								
IROW	I	22.		23.	30.	35.						
ISTOP	I	12.		13.	14.	44.	45.	46.				
IX	I	37.		39.								
IY	I	35.		36.								
K	I	10.		21.								
NEW	I	4.	DATA	60.								
NRAD	I	41.		42.	52.							
NSLICE	I	15.		16.	47.	48.						
OLD	I	2.	DATA	4.	61.							
R	R	11.		13.	15.	17.	43.	45.	47.	51.	53.	54.
RAD	R	3.	D	41.	43.	54.						
RADIUS	R	41.	SUBROUTINE									
STORE2	R	15.	SUBROUTINE	47.								
WAY	I	2.		59.	60.	61.						
XCEN	R	11.		13.	15.	17.	39.	40.	41.	45.	47.	
XMAX	R	22.		23.	29.							
XMIN	R	22.		23.	29.	39.						
YCEN	R	11.		13.	15.	17.	36.	40.	41.	45.	47.	
YMAX	R	22.		23.	34.	36.						
YMIN	R	22.		23.	34.							

FORSTAT Listing of Program SLOPE3

```
1.          PROGRAM SLOPE3(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      C    ------------------------------------------------------------------
      C                                 PROGRAM SLOPE3
      C    ------------------------------------------------------------------
      C    PURPOSE-
      C         TO ANALYZE A SLOPE PROFILE FOR A CIRCULAR TYPE OF FAILURE
      C    USING AN ADJUSTED FORM OF THE MODIFIED BISHOP FACTOR OF SAFETY.
      C    ------------------------------------------------------------------
      C    CONTROL CARDS-
      C
      C    ALL FORMATS ARE INTEGER OR FIXED POINT DEPENDING UPON FORTRAN
      C    CODING OF VARIABLES, UNLESS OTHERWISE STATED.
      C    INPUT MUST BE IN THE FOLLOWING UNITS.
      C         LENGTH IN FEET.
      C         FORCE IN POUNDS.
      C         ANGLE IN DEGREES.
      C
      C    (A) DESCRIPTION OF PROFILE-
      C              SEE SUBROUTINE  INOUT.
      C
      C    (B) DESCRIPTION OF SLIP SURFACE/SEARCH-
      C         (1) OPTION CARD
      C              IOPT  (COL 1) IF IOPT=1, INDIVIDUAL CIRCLE ANALYSIS.
      C                            IF IOPT=2, GRID ANALYSIS.
      C              INUM  (COL 2-3) NUMBER OF CIRCLES TO BE READ OR NUMBER OF
      C                              GRIDS TO BE READ DEPENDING UPON IOPT.
      C
      C         (2) SLIP SURFACE/SEARCH PARAMETER CARD(S)
      C
      C    COMPLETE EITHER 2A OR 2B DEPENDING UPON THE IOPT VALUE.  THERE MUST
      C    BE INUM TOTAL CARDS IN EITHER CASE.
      C
      C              (2A) INDIVIDUAL CIRCLE ANALYSIS CARD
      C                   XCEN (COL 1-10)  X-CENTER OF CIRCLE.
      C                   YCEN (COL 11-20) Y-CENTER OF CIRCLE.
      C                   R    (COL 21-30) RADIUS OF CIRCLE.
      C
      C              (2B) GRID ANALYSIS CARD
      C                   XMAX (COL 1-10)  MAXIMUM X-COORD OF GRID.
      C                   XMIN (COL 11-20) MINIMUM X-COORD OF GRID.
      C                   YMAX (COL 21-30) MAXIMUM Y-COORD OF GRID.
      C                   YMIN (COL 31-40) MINIMUM Y-COORD OF GRID.
      C                   DRAD (COL 41-50) RADIUS INCREMENT VALUE.
      C                   ICOL (COL 51-52) NUMBER OF COLUMNS IN GRID.
      C                   IROW (COL 53-54) NUMBER OF ROWS IN GRID.
      C
      C    (C) TRANSFER OF CONTROL-
      C         (1) CONTROL OPTION CARD
      C              WAY  (COL 1-3) IF WAY=NEW, CONTROL IS TRANSFERRED TO (A).
      C                             IF WAY=OLD, CONTROL IS TRANSFERRED TO (B).
      C                             IF WAY=END, PROGRAM IS TERMINATED.
      C
      C    ------------------------------------------------------------------
      C    REQUIRED ROUTINES-
      C         SUBROUTINE STORE3
      C         SUBROUTINE INOUT
      C         SUBROUTINE CROSS
      C         SUBROUTINE RADIUS
      C         SUBROUTINE FACTOR
      C         SUBROUTINE WEIGHT        (CALLED BY STORE3)
      C         FUNCTION HEAD            (CALLED BY STORE3)
      C    ------------------------------------------------------------------
      C    SYSTEM ROUTINES-
      C         FUNCTION FLOAT
      C    ------------------------------------------------------------------
2.          INTEGER OLD,WAY
3.          DIMENSION RAD(15)
4.          DATA NEW,OLD/3HNEW,3HOLD/
5.     5    CALL INOUT (3)
6.    10    READ (5,130) IOPT,INUM
7.          GO TO (15,30), IOPT
      C    ---------------------------------
      C    INDIVIDUAL CIRCLE OPTION
      C    ---------------------------------
8.    15    WRITE (6,135) INUM
9.          WRITE (6,140)
```

```
          DO 25 K=1,INUM                                                  SL3 154
             READ (5,145) XCEN,YCEN,R                                     SL3 156
             ISTOP=1                                                      SL3 158
             CALL CROSS (ISTOP,XCEN,YCEN,R)                               SL3 160
             GO TO (20,25), ISTOP                                         SL3 162
   20        CALL STORE3 (XCEN,YCEN,R,NSLICE)                             SL3 164
             CALL FACTOR (NSLICE,FMYB)                                    SL3 166
             WRITE (6,150) XCEN,YCEN,R,FMYB                               SL3 168
   25     CONTINUE                                                        SL3 170
          GO TO 115                                                       SL3 172
C                                                                         SL3 174
C     ---------------------------------                                   SL3 176
C     GRID OPTION                                                         SL3 178
C     ---------------------------------                                   SL3 180
   30     WRITE (6,155) INUM                                              SL3 182
          DO 110 K=1,INUM                                                 SL3 184
             READ (5,160) XMAX,XMIN,YMAX,YMIN,DRAD,ICOL,IROW              SL3 186
             WRITE (6,165) XMAX,YMAX,XMIN,YMIN,ICOL,IROW,DRAD             SL3 188
             WRITE (6,140)                                                SL3 190
             DX=FLOAT(ICOL-1)                                             SL3 192
             IF (DX) 35,35,40                                             SL3 194
   35        DX=1.0                                                       SL3 196
             GO TO 45                                                     SL3 198
C                                                                         SL3 200
   40        DX=(XMAX-XMIN)/DX                                            SL3 202
   45        DY=FLOAT(IROW-1)                                             SL3 204
             IF (DY) 50,50,55                                             SL3 206
   50        DY=1.0                                                       SL3 208
             GO TO 60                                                     SL3 210
C                                                                         SL3 212
   55        DY=(YMAX-YMIN)/DY                                            SL3 214
   60        DO 105 IY=1,IROW                                             SL3 216
                YCEN=YMAX-FLOAT(IY-1)*DY                                  SL3 218
                DO 100 IX=1,ICOL                                          SL3 220
                   FMIN=999999.                                           SL3 222
                   XCEN=XMIN+FLOAT(IX-1)*DX                               SL3 224
                   WRITE (6,170) XCEN,YCEN                                SL3 226
                   CALL RADIUS (XCEN,YCEN,RAD,NRAD)                       SL3 228
                   DO 95 I=1,NRAD                                         SL3 230
                      R=RAD(I)                                            SL3 232
   65                 ISTOP=1                                             SL3 234
                      CALL CROSS (ISTOP,XCEN,YCEN,R)                      SL3 236
                      GO TO (70,85), ISTOP                                SL3 238
   70                 CALL STORE3 (XCEN,YCEN,R,NSLICE)                    SL3 240
                      CALL FACTOR (NSLICE,FMYB)                           SL3 242
                      IF (FMYB-FMIN) 75,80,80                             SL3 244
   75                 FMIN=FMYB                                           SL3 246
   80                 WRITE (6,175) R,FMYB                                SL3 248
   85                 IF (I-NRAD) 90,95,95                                SL3 250
   90                 R=R+DRAD                                            SL3 252
                      IF (R-RAD(I+1)) 65,95,95                            SL3 254
   95              CONTINUE                                               SL3 256
  100           WRITE (6,190) FMIN                                        SL3 258
  105        WRITE (6,180)                                                SL3 260
  110     CONTINUE                                                        SL3 262
C     ---------------------------------                                   SL3 264
C     DETERMINE TRANSFER OF CONTROL                                       SL3 266
C     ---------------------------------                                   SL3 268
  115     READ (5,185) WAY                                                SL3 270
          IF (WAY-NEW) 120,5,120                                          SL3 272
  120     IF (WAY-OLD) 125,10,125                                         SL3 274
  125     STOP                                                            SL3 276
C                                                                         SL3 278
  130     FORMAT (I1,I2)                                                  SL3 280
  135     FORMAT (1H1///4X,#INDIVIDUAL CIRCLE OPTION SPECIFIED#/13X,I3,# CIRSL3 282
         1CLES TO BE ANALYZED#//)                                         SL3 284
  140     FORMAT (1H /8X,#X-CENTER#,5X,#Y-CENTER#,5X,#RADIUS#,10X,#FS#//) SL3 286
  145     FORMAT (3F10.4)                                                 SL3 288
  150     FORMAT (1H 6X,F8.1,5X,F8.1,4X,F8.2,F15.3)                       SL3 290
  155     FORMAT (1H1///4X,#GRID OPTION SPECIFIED#/13X,I3,# GRIDS TO BE ANALSL3 292
         1YZED#//)                                                        SL3 294
  160     FORMAT (5F10.0,2I2)                                             SL3 296
  165     FORMAT (1H ////10X,#GRID SPECIFICATIONS#//12X,#XMAX =#,F10.1,10X,#SL3 298
         1YMAX =#,F10.1/12X,#XMIN =#,F10.1,10X,#YMIN =#,F10.1/12X,#ICOL =#,ISL3 300
         210,10X,#IROW =#,I10//12X,#RADIUS INCREMENT =#,F10.1/)           SL3 302
  170     FORMAT (1H /8X,F8.1,5X,F8.1)                                    SL3 304
  175     FORMAT (1H 32X,F8.2,F13.3)                                      SL3 306
  180     FORMAT (1H //)                                                  SL3 308
  185     FORMAT (A3)                                                     SL3 310
  190     FORMAT (1H 14X,#MINIMUM FS FOR THIS CENTER = #,F10.3)           SL3 312
          END                                                             SL3 314
```

STATEMENT NUMBER	DEFINITION		REFERENCES		
5	5.		60.		
10	6.		61.		
15	8.		7.		
20	15.		14.		
25	18.		10.	14.	
30	20.		7.		
35	27.		26.		
40	29.		26.		
45	30.		28.		
50	32.		31.		
55	34.		31.		
60	35.		33.		
65	44.		54.		
70	47.		46.		
75	50.		49.		
80	51.		49.		
85	52.		46.		
90	53.		52.		
95	55.		42.	52.	54.
100	56.		37.		
105	57.		35.		
110	58.		21.		
115	59.		19.		
120	61.		60.		
125	62.		61.		
130	63.	FORMAT	6.		
135	64.	FORMAT	8.		
140	65.	FORMAT	9.	24.	
145	66.	FORMAT	11.		
150	67.	FORMAT	17.		
155	68.	FORMAT	20.		
160	69.	FORMAT	22.		
165	70.	FORMAT	23.		
170	71.	FORMAT	40.		
175	72.	FORMAT	51.		
180	73.	FORMAT	57.		
185	74.	FORMAT	59.		
190	75.	FORMAT	56.		

LABEL	TYPE	DEFINITION			REFERENCES								
CROSS	R	13.		SUBROUTINE	45.								
DRAD	R	22.			23.	53.							
DX	R	25.			26.	27.	29.	39.					
DY	R	30.			31.	32.	34.	36.					
FACTOR	R	16.		SUBROUTINE	48.								
FLOAT	R	25.		FUNCTION	30.	36.	39.						
FMIN	R	38.			49.	50.	56.						
FMYB	R	16.			17.	48.	49.	50.	51.				
I	I	42.			43.	52.	54.						
ICOL	I	22.			23.	25.	37.						
INOUT	I	5.		SUBROUTINE									
INUM	I	6.			8.	10.	20.	21.					
IOPT	I	6.			7.								
IROW	I	22.			23.	30.	35.						
ISTOP	I	12.			13.	14.	44.	45.	46.				
IX	I	37.			39.								
IY	I	35.			36.								
K	I	10.			21.								
NEW	I	4.		DATA	60.								
NRAD	I	41.			42.	52.							
NSLICE	I	15.			16.	47.	48.						
OLD	I	2.		DATA	4.	61.							
H	R	11.			13.	15.	17.	43.	45.	47.	51.	53.	56.
RAD	R	3.	D		41.	43.	54.						
RADIUS	R	41.		SUBROUTINE									
STORE3	R	15.		SUBROUTINE	47.								
WAY	I	2.			59.	60.	61.						
XCEN	R	11.			13.	15.	17.	39.	40.	41.	45.	47.	
XMAX	R	22.			23.	29.							
XMIN	R	22.			23.	29.	39.						
YCEN	R	11.			13.	15.	17.	36.	40.	41.	45.	47.	
YMAX	R	22.			23.	34.	36.						
YMIN	R	22.			23.	34.							

FORSTAT Listing of Program SLOPE4

```
1.      PROGRAM SLOPE4(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     ------------------------------------------------------------------
C                                  PROGRAM SLOPE4
C     ------------------------------------------------------------------
C     PURPOSE-
C          TO ANALYZE A SLOPE PROFILE FOR AN IRREGULAR TYPE OF FAILURE
C     SURFACE USING AN ADJUSTED FORM OF THE MODIFIED BISHOP FACTOR OF
C     SAFETY.
C     ------------------------------------------------------------------
C     CONTROL CARDS-
C
C     ALL FORMATS ARE INTEGER OR FIXED POINT DEPENDING UPON FORTRAN
C     CODING OF VARIABLES.
C     INPUT MUST BE IN THE FOLLOWING UNITS.
C          LENGTH IN FEET.
C          FORCE IN POUNDS.
C          ANGLE IN DEGREES.
C
C     (A) DESCRIPTION OF PROFILE-
C          SEE SUBROUTINE INOUT.
C
C     (B) DESCRIPTION OF SLIP SURFACE/SEARCH-
C          (1) OPTION CARD
C               IOPT (COL 1) IF IOPT=1, INDIVIDUAL IRREGULAR SURFACE
C                                       ANALYSIS.
C                            IF IOPT=2, IRREGULAR SURFACE SEARCH ANALYSIS.
C               INUM (COL 2-3) NUMBER OF SURFACES TO BE READ OR NUMBER OF
C                              SEARCH PARAMETERS TO BE READ DEPENDING
C                              UPON IOPT.
C
C          (2) SLIP SURFACE/SEARCH PARAMETER CARD(S)
C
C     COMPLETE EITHER 2A OR 2B DEPENDING UPON THE IOPT VALUE.  BUT IN
C     EITHER CASE ENTER INUM TIMES.
C
C               (2A) INDIVIDUAL SURFACE ANALYSIS CARDS
C                    (1) PARAMETER CARD
C                         NPTS (COL 1-2) NUMBER OF POINTS DEFINING  SLIP
C                                        SURFACE.
C                    (2) COORDINATE CARD(S)
C                    ENTER COORDINATES FROM LEFT TO RIGHT.
C                         X(I) (COL 1-10)  X-COORD OF POINT.
C                         Y(I) (COL 11-20) Y-COORD OF POINT.
C                         REPEAT, FILLING ALL 80 COLUMNS OF CARD.
C
C               (2B) IRREGULAR SEARCH CARD
C                    (1) SEARCH PARAMETER CARD
C                         YMAX (COL 1-10)  MAXIMUM Y-COORD OF IMAGINARY
C                                          LAYERING.
C                         YMIN (COL 11-20) MINIMUM Y-COORD OF IMAGINARY
C                                          LAYERING.
C                         XMAX (COL 21-30) MAXIMUM ALLOWABLE X-COORD OF
C                                          EXIT POINT.
C                         XMIN (COL 31-40) MINIMUM ALLOWABLE X-COORD OF
C                                          EXIT POINT.
C                         XCONTROL (COL 41-50) CONTROL POINT FOR SEARCH.
C                         NMIN (COL 51) MINIMUM NUMBER OF IMAGINARY
C                                       LAYERS.
C                         NMAX (COL 52-53) MAXIMUM NUMBER OF IMAGINARY
C                                          LAYERS.
C                         NSUR (COL 54-55) NUMBER OF SURFACES TO BE
C                                          ANALYZED IN THE RANGE XMAX TO
C                                          XMIN. (MUST BE .GE. 2)
C
C     (C) TRANSFER OF CONTROL-
C          (1) CONTROL OPTION CARD
C               WAY (COL 1-3) IF WAY=NEW, CONTROL IS TRANSFERRED TO (A).
C                             IF WAY=OLD, CONTROL IS TRANSFERRED TO (B).
C                             IF WAY=END, PROGRAM IS TERMINATED.
C
C     ------------------------------------------------------------------
C     SUPPORTING ROUTINES-
C          SUBROUTINE STORE4
C          SUBROUTINE INOUT
C          SUBROUTINE SLPBND
```

```
C          SUBROUTINE FACTOR
C          SUBROUTINE WEIGHT           (CALLED BY STORE4)
C          FUNCTION READ               (CALLED BY STORE4)
C     ---------------------------------------------------------------------
C     SYSTEM ROUTINES-
C          FUNCTION COS
C          FUNCTION ABS
C          FUNCTION FLOAT
C     ---------------------------------------------------------------------
C     NOTE-
C          IN ORDER TO ACCOUNT FOR MACHINE ROUNDING, A DIFFERENCE BETWEEN
C     TWO VARIABLES OF LESS THAN 10.E-4 IS TAKEN AS EQUAL TO ZERO.  THIS
C     VALUE IS DEFINED IN THE DATA STATEMENT.
C     ---------------------------------------------------------------------
      INTEGER OLD,WAY
      DIMENSION SERIES(10), B(3), BETA(3)
      COMMON DUM1(23),XTOP,DUM2(2),IDUM1,NTOP,IDUM2(19),BNDS(20,4)
      COMMON EQ(20,2),DUM3(312),X(12),Y(12),SEQ(11,2)
      DATA (B(I),BETA(I),I=1,3)/30.,.57735,45.,1.,60.,1.7321/
      DATA (SERIES(I),I=1,10)/1.,2.,3.,5.,8.,13.,21.,34.,55.,89./
      DATA PI2,PI180,ZERO,NEW,OLD/1.570796,0.017453,10.E-4,3HNEW,3HOLD/
      EQUIVALENCE (X(2),XCONT), (Y(2),YMIN)
    5 CALL INOUT (3)
   10 READ (5,205) IOPT,INUM
      GO TO (15,30), IOPT
C     -------------------------------
C     INDIVIDUAL SURFACE OPTION
C     -------------------------------
   15 WRITE (6,210) INUM
      WRITE (6,215)
      DO 25 K=1,INUM
         READ (5,220) NLINES
         READ (5,225) (X(I),Y(I),I=1,NLINES)
         DO 20 I=2,NLINES
            SEQ(I-1,1)=(Y(I)-Y(I-1))/(X(I)-X(I-1))
   20    SEQ(I-1,2)=Y(I)-SEQ(I-1,1)*X(I)
         CALL SLPRND (2,NLINES)
         CALL STORE4 (NSLICE,2,NLINES)
         CALL FACTOR (NSLICE,FMYR)
   25 WRITE (6,230) FMYR,(X(I),Y(I),I=1,NLINES)
      GO TO 190
C
C     -------------------------------
C     IRREGULAR SURFACE SEARCH OPTION
C     -------------------------------
   30 WRITE (6,235) INUM
      DO 185 KNUM=1,INUM
         READ (5,240) YMAX,YMIN,XMAX,XMIN,XCONT,NMIN,NMAX,NSUR
         WRITE (6,245) XMIN,YMIN,NSUR,XMAX,YMAX,XCONT,NMIN,NMAX
         DX=(XMAX-XMIN)/FLOAT(NSUR-1)
         MM=1
         ILOW=2
         DO 40 I=1,NTOP
            IF (XCONT-BNDS(I,1)) 40,35,35
   35       IF (XCONT-BNDS(I,3)) 45,40,40
   40    CONTINUE
         STOP
   45    YIT=EQ(I,1)*XCONT+EQ(I,2)
         IF (YIT-YMIN-ZERO) 55,50,50
   50    ILOW=1
         MM=3
C     -------------------------------
C       VARY THE NUMBER OF IMAGINARY LAYERS
C     -------------------------------
   55    DO 180 NL=NMIN,NMAX
            WRITE (6,250) NL
            GO TO (60,65), ILOW
   60       WRITE (6,255)
            GO TO 70
C
   65       WRITE (6,260)
   70       NL1=NL+2
            H=YMAX-YMIN
C     -------------------------------
C     DETERMINE Y COORDS. OF SLIP SURFACE
C     -------------------------------
            SUMM=0.0
            DO 75 I=3,NL1
               Y(I)=H*(1.-COS(FLOAT(I-2)*PI2/FLOAT(NL)))+YMIN
   75       SUMM=SUMM+(Y(I)-Y(I-1))/SERIES(I-2)
```

```
C     ---------------------------------------
C     VARY THE INITIAL ANGLE
C     ---------------------------------------
                 XNEW=XMAX
                 GO TO 85
C
 80              XNEW=XNEW-DX
 85              ANG=SUMM/(XNEW-XCONT)
C     ---------------------------------------
C     DETERMINE THE X COORDS. OF SLIP SURFACE
C     ---------------------------------------
                 DO 90 J=3,NL1
                    X(J)=X(J-1)+(Y(J)-Y(J-1))/(ANG*SERIES(J-2))
                    SEQ(J-1,1)=(Y(J)-Y(J-1))/(X(J)-X(J-1))
 90              SEQ(J-1,2)=Y(J)-SEQ(J-1,1)*X(J)
C     ---------------------------------------
C     FIT SLIP SURFACE TO PROFILE
C     ---------------------------------------
                 DO 120 JJ=1,NL
                    J=NL-JJ+3
                    DO 115 LL=1,NTOP
                       L=NTOP-LL+1
                       IF (XTOP-BNDS(L,1)) 95,95,120
 95                    TEMP=EQ(L,1)-SEQ(J-1,1)
                       IF (ABS(TEMP)-ZERO) 115,115,100
 100                   XI=(SEQ(J-1,2)-EQ(L,2))/TEMP
                       IF (XI-X(J-1)) 115,105,105
 105                   IF (XI-BNDS(L,1)) 115,110,110
 110                   IF (XI-BNDS(L,3)) 125,125,80
 115                CONTINUE
 120             CONTINUE
                 GO TO 180
C
 125             NLT=1
                 IF (XI-XMIN+ZERO) 180,135,130
 130             IF (XI-XMAX-ZERO) 135,135,80
 135             X(NLT)=XI
                 Y(NLT)=XI*EQ(L,1)+EQ(L,2)
                 SEQ(NLT-1,1)=(Y(NLT)-Y(NLT-1))/(X(NLT)-X(NLT-1))
                 SEQ(NLT-1,2)=Y(NLT)-SEQ(NLT-1,1)*X(NLT)
                 DO 170 J=1,MM
                    GO TO (140,160), ILOW
 140                H=BETA(J)*XCONT+YMIN
                    DO 150 L=1,NTOP
                       XI=(H-EQ(L,2))/(EQ(L,1)+BETA(J))
                       IF (XI-BNDS(L,1)) 150,145,145
 145                   IF (XI-BNDS(L,3)) 155,155,150
 150                CONTINUE
                    GO TO 170
C
 155                X(1)=XI
                    Y(1)=XI*EQ(L,1)+EQ(L,2)
                    SEQ(1,1)=(Y(2)-Y(1))/(X(2)-X(1))
                    SEQ(1,2)=Y(1)-X(1)*SEQ(1,1)
C     ---------------------------------------
C     CALCULATE FACTOR OF SAFETY FOR CURRENT SURFACE
C     ---------------------------------------
 160                CALL SLPBND (ILOW+1,NLT)
                    CALL STORE4 (NSLICE,ILOW+1,NLT)
                    CALL FACTOR (NSLICE,FMYB)
                    GO TO (165,175), ILOW
 165                WRITE (6,265) XNEW,B(J),FMYB,(X(I),Y(I),I=ILOW,NLT)
 170             CONTINUE
                 WRITE (6,270)
                 GO TO 80
C
 175             WRITE (6,275) XNEW,FMYB,(X(I),Y(I),I=ILOW,NLT)
                 GO TO 80
C
 180        WRITE (6,270)
            WRITE (6,280)
 185   CONTINUE
```

```
      C     -----------------------------------                         SL4 456
      C     DETERMINE TRANSFER OF CONTROL                               SL4 458
      C     -----------------------------------                         SL4 460
      190   READ (5,685) WAY                                            SL4 462
            IF (WAY-NEW) 195,5,195                                      SL4 464
      195   IF (WAY-OLD) 200,10,200                                     SL4 466
      200   STOP                                                        SL4 468
      C                                                                 SL4 470
      205   FORMAT (I1,I2)                                              SL4 472
      210   FORMAT (1H1//4X,#INDIVIDUAL IRREGULAR SURFACE OPTION SPECIFIED#/13SL4 474
           1X,I3,# SURFACES TO BE ANALYZED#)                            SL4 476
      215   FORMAT (1H ///5X,#FS#,6X,#(X(1),Y(1)),...,#/)               SL4 478
      220   FORMAT (I2)                                                 SL4 480
      225   FORMAT (8F10.0)                                             SL4 482
      230   FORMAT (1H F8.3,5X,4(F8.2,2X,F8.2,5X)/14X,4(F8.2,2X,F8.2,5X)/14X,3SL4 484
           1(F8.2,2X,F8.2,5X))                                          SL4 486
      235   FORMAT (1H1//4X,#SEARCH IRREGULAR SURFACE OPTION SPECIFIED#/13X,I3SL4 488
           1,# SEARCHES TO BE ANALYZED#)                                SL4 490
      240   FORMAT (5F10.0,I1,2I2)                                      SL4 492
      245   FORMAT (1H ////10X,#SEARCH SPECIFICATIONS#//12X,#XMIN =#,F10.1,10XSL4 494
           1,#YMIN =#,F10.1/12X,#NSUR =#,I10/12X,#XMAX =#,F10.1,10X,#YMAX =#,FSL4 496
           210.1//12X,#X-CONTROL =#,F10.1//12X,#NMIN =#I10/12X,#NMAX =#,I10)  SL4 498
      250   FORMAT (1H /////2X,#NLAYER =#,I3/)                          SL4 500
      255   FORMAT (1H 1X,#X-EXIT#,3X,#R#,5X,#FS#,10X,#(X(1),Y(1)),...,#/)   SL4 502
      260   FORMAT (1H 1X,#X-EXIT#,5X,#FS#,10X,#(X(1),Y(1)),...,#/)     SL4 504
      265   FORMAT (1H F8.2,F4.0,F7.3,5X,4(5X,2F10.2)/25X,4(5X,2F10.2)/25X,4(5SL4 506
           1X,2F10.2))                                                  SL4 508
      270   FORMAT (1H )                                                SL4 510
      275   FORMAT (1H F8.2,F7.3,5X,4(5X,2F10.2)/21X,4(5X,2F10.2)/21X,4(5X,2F1SL4 512
           10.2))                                                       SL4 514
      280   FORMAT (1H ////)                                            SL4 516
      285   FORMAT (A3)                                                 SL4 518
            END                                                         SL4 520
```

STATEMENT NUMBER	DEFINITION		REFERENCES			
5	10.		110.			
10	11.		111.			
15	13.		12.			
20	20.		18.			
25	24.		15.			
30	26.		12.			
35	35.		34.			
40	36.		33.	34.	35.	
45	38.		35.			
50	40.		39.			
55	42.		39.			
60	45.		44.			
65	47.		44.			
70	48.		46.			
75	53.		51.			
80	56.		72.	78.	103.	105.
85	57.		55.			
90	61.		58.			
95	67.		66.			
100	69.		68.			
105	71.		70.			
110	72.		71.			
115	73.		64.	68.	70.	71.
120	74.		62.	66.		
125	76.		72.			
130	78.		77.			
135	79.		77.	78.		
140	85.		84.			
145	89.		88.			
150	90.		86.	88.	89.	
155	92.		89.			
160	96.		84.			
165	100.		99.			
170	101.		83.	91.		
175	104.		99.			
180	106.		42.	75.	77.	
185	108.		27.			
190	109.		25.			
195	111.		110.			
200	112.		111.			
205	113.	FORMAT	11.			
210	114.	FORMAT	13.			
215	115.	FORMAT	14.			
220	116.	FORMAT	16.			
225	117.	FORMAT	17.			
230	118.	FORMAT	24.			
235	119.	FORMAT	26.			
240	120.	FORMAT	28.			
245	121.	FORMAT	29.			
250	122.	FORMAT	43.			
255	123.	FORMAT	45.			
260	124.	FORMAT	47.			
265	125.	FORMAT	100.			
270	126.	FORMAT	102.	106.		
275	127.	FORMAT	104.			
280	128.	FORMAT	107.			
285	129.	FORMAT	109.			

LABEL	TYPE	DEFINITION		REFERENCES
ABS	R	68.	FUNCTION	
ANG	R	57.		59.
B	R	3. D	DATA	6. 100.
BETA	R	3. D	DATA	6. 85. 97.
BNOR	R	4. CD		34. 35. 66. 71. 72. 88. 89.
COS	R	52.	FUNCTION	
DUM1	R	4. CD		
DUM2	R	4. CD		
DUM3	R	5. CD		
DX	R	30.		56.
EQ	R	5. CD		38. 57. 69. 80. 87. 93.
FACTOR	R	23.	SUBROUTINE	98.
FLOAT	R	30.	FUNCTION	52.
FMYA	R	23.		24. 98. 100. 104.
FR	R	120.		
H	R	49.		52. 85. 97.
I	I	6.	DATA	7. 17. 18. 19. 20. 24. 33. 34. 35. 38. 51. 52. 53. 100. 104.
IDUM1	I	4. C		
IDUM2	I	4. CD		
ILOW	I	32.		40. 44. 84. 96. 97. 99. 100. 104.
INOUT	I	10.	SUBROUTINE	
INUM	I	11.		13. 15. 26. 27.
IOPT	I	11.		12.
J	I	58.		59. 60. 61. 63. 67. 69. 70. 76. 83. 85. 87. 100.
JJ	I	62.		63.
K	I	15.		
KNUM	I	27.		
L	I	65.		66. 67. 69. 71. 72. 80. 86. 87. 88. 89. 93.
LL	I	64.		65.
MM	I	31.		41. 83.
NEW	I	8.	DATA	110.
NL	I	42.		43. 48. 52. 62. 63.
NLINES	I	16.		17. 18. 21. 22. 24.
NLT	I	76.		79. 80. 81. 82. 96. 97. 100. 104.
NL1	I	48.		51. 58.
NMAX	I	28.		29. 42.
NMIN	I	28.		29. 42.
NSLICE	I	22.		23. 97. 98.
NSUR	I	28.		29. 30.
NTOP	I	4. C		33. 64. 65. 86.
OLD	I	2.	DATA	8. 111.
PI180	R	8.	DATA	
PI2	R	8.	DATA	52.
SEQ	R	5. CD		19. 20. 60. 61. 67. 69. 81. 82. 94. 95.
SERIES	R	3. D	DATA	7. 53. 59.
SLPPNO	R	21.	SUBROUTINE	96.
STORE4	R	22.	SUBROUTINE	97.
SUMM	R	50.		53. 57.
TEMP	R	67.		68. 69.
WAY	I	2.		109. 110. 111.
X	R	5. CDE		9. 17. 19. 20. 24. 59. 60. 61. 70. 70. 81. 82. 92. 94. 95. 100. 104.
XCONT	R	9. E		28. 29. 34. 35. 38. 57. 85.
XI	R	69.		70. 71. 72. 77. 78. 79. 80. 87. 88. 89. 92. 93.
XMAX	R	28.		29. 30. 54. 78.
XMIN	R	28.		29. 30. 77.
XNEW	R	54.		56. 57. 100. 104.
XTOP	R	4. C		66.
Y	R	5. CDE		9. 17. 19. 20. 24. 52. 53. 59. 60. 61. 80. 81. 82. 93. 94. 95. 100. 104.
YIT	R	38.		39.
YMAX	R	29.		29. 49.
YMIN	R	9. E		28. 29. 39. 49. 52. 85.
ZERO	R	8.	DATA	39. 68. 77. 78.

FORSTAT Listing of Program FLWNET

```
 1.          PROGRAM FLWNET(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
        C    ------------------------------------------------------------------
        C                          PROGRAM FLWNET
        C    ------------------------------------------------------------------
        C    PURPOSE-
        C         TO APPROXIMATE A FLOWNET WITH A 5TH ORDER POLYNOMIAL.
        C    ------------------------------------------------------------------
        C    CONTROL CARDS-
        C
        C         (1) PARAMETER CARD
        C              NTOT (COL 1-3) TOTAL NUMBER OF POINTS TO BE READ.
        C
        C         (2) DATA CARDS
        C         THIS SET INCLUDES ONE CARD/COORDINATE POINT.
        C              X(I) (COL 1-10)  X-COORD OF POINT
        C              Y(I) (COL 11-20) Y-COORD OF POINT
        C              Z(I) (COL 21-30) TOTAL HEAD
        C
        C    ------------------------------------------------------------------
        C    SUPPORTING ROUTINES-
        C         FUNCTION HEAD
        C    ------------------------------------------------------------------
        C    SYSTEM ROUTINES-
        C         FUNCTION ABS
        C         FUNCTION SQRT
        C         FUNCTION FLOAT
        C    ------------------------------------------------------------------
        C    NOTE-
        C         THIS PROGRAM IS A MODIFICATION FROM #GCARS#, BY A.K.TURNER.
        C    ------------------------------------------------------------------
 2.          DIMENSION XINV(21,21), AM(21,22), PAR(21), BB(21), N(21)
 3.          DIMENSION X(100), Y(100), Z(100)
 4.          COMMON A(21)
 5.          EQUIVALENCE (A,PAR)
 6.          SSZ=0.0
 7.          ZSUM=0.0
 8.          PAR(1)=1.0
 9.          DO 10 I=1,21
10.             DO 5 J=1,21
11.     5       AM(I,J)=0.0
12.             N(I)=0
13.     10   BB(I)=0.0
        C    ---------------------------------
        C    READ DATA
        C    ---------------------------------
14.          READ (5,190) NTOT
15.          DO 25 L=1,NTOT
16.             READ (5,185) X(L),Y(L),Z(L)
17.             PAR(2)=X(L)
18.             PAR(3)=Y(L)
19.             PAR(4)=X(L)*X(L)
20.             PAR(5)=X(L)*Y(L)
21.             PAR(6)=Y(L)*Y(L)
22.             PAR(7)=PAR(4)*X(L)
23.             PAR(8)=PAR(4)*Y(L)
24.             PAR(9)=PAR(6)*X(L)
25.             PAR(10)=PAR(6)*Y(L)
26.             PAR(11)=PAR(7)*X(L)
27.             PAR(12)=PAR(7)*Y(L)
28.             PAR(13)=PAR(4)*PAR(6)
29.             PAR(14)=PAR(10)*X(L)
30.             PAR(15)=PAR(10)*Y(L)
31.             PAR(16)=PAR(11)*X(L)
32.             PAR(17)=PAR(11)*Y(L)
33.             PAR(18)=PAR(7)*PAR(6)
34.             PAR(19)=PAR(10)*PAR(4)
35.             PAR(20)=PAR(15)*X(L)
36.             PAR(21)=PAR(15)*Y(L)
        C    ---------------------------------
        C    DEVELOP XY-TRANSPOSE*XY MATRIX
        C    ---------------------------------
37.             DO 15 I=1,21
38.             DO 15 J=1,21
39.     15      AM(I,J)=AM(I,J)+PAR(I)*PAR(J)
```

```
      C     ---------------------------------
      C     DEVELOP XY-TARNSPOSE*Z MATRIX
      C     ---------------------------------
                DO 20 I=1,21
      20        BB(I)=BB(I)+Z(L)*PAR(I)
                SSZ=SSZ+Z(L)*Z(L)
      25      ZSUM=ZSUM+Z(L)
              DO 30 I=1,20
                IP1=I+1
              DO 30 J=IP1,21
      30      AM(J,I)=AM(I,J)
              DO 105 J=1,21
                I=1
                JJ=J-1
      35        DO 40 L=1,JJ
                  IF (N(L)-I) 40,45,40
      40        CONTINUE
                IF (AM(I,1)) 55,45,55
      45        I=I+1
                IF (21-I) 50,35,35
      50        WRITE (6,180)
                STOP
      55        AMA=ABS(AM(I,1))
                II=I
      60        II=II+1
                IF (21-II) 80,65,65
      65        DO 70 IZ=1,J
                  IF (N(IZ)-II) 70,60,70
      70        CONTINUE
                AMB=ABS(AM(II,1))
      C     ---------------------------------
      C     TEST FOR MAXIMAL SIZE PIVOTAL ELEMENT
      C     ---------------------------------
                IF (AMA-AMB) 75,60,60
      75        AMA=AMB
                I=II
                GO TO 60
      C
      80        N(J)=I
                DO 85 IZ=1,21
      85        AM(IZ,22)=0.0
                AM(I,22)=1.0
                DA=AM(I,1)
      C     ---------------------------------
      C     NORMALIZE THE PIVOTAL ROW
      C     ---------------------------------
                DO 90 IZ=2,22
      90        AM(I,IZ-1)=AM(I,IZ)/DA
              DO 105 IZ=1,21
                IF (IZ-I) 95,105,95
      95        DB=AM(IZ,1)
      C     ---------------------------------
      C     ZERO OUT NON-PIVOTAL COLUMN ELEMENTS
      C     ---------------------------------
                DO 100 JZ=2,22
      100       AM(IZ,JZ-1)=AM(IZ,JZ)-AM(I,JZ-1)*DB
      105     CONTINUE
              DO 120 I=1,21
                DO 110 J=1,21
                  IF (N(J)-I) 110,115,110
      110       CONTINUE
      115     DO 120 L=1,21
                LL=N(L)
      120     XINV(L,I)=AM(LL,J)
              DO 125 I=1,21
                A(I)=0.0
              DO 125 J=1,21
      125     A(I)=A(I)+XINV(I,J)*BB(J)
      C     ---------------------------------
      C     PRINT RESULTS
      C     ---------------------------------
              WRITE (6,175)
              WRITE (6,150)
              DO 130 I=1,21
      130     WRITE (6,155) I,A(I)
```

```
          WRITE (6,160)
          WRITE (6,185)
          DO 135 I=1,NTOT
             EST=HEAD(X(I),Y(I))
             DELTA=EST-Z(I)
 135      WRITE (6,170) I,X(I),Y(I),Z(I),EST,DELTA
          ZBAR=ZSUM/FLOAT(NTOT)
          SSZBAR=ZSUM*ZBAR
          SSZ=SSZ-SSZBAR
          SSR=0.0
          DO 140 I=1,21
 140      SSR=SSR+A(I)*BB(I)
          SSR=SSR-SSZBAR
          RR=SSR/SSZ
          PCENT=RR*100.
          R=SQRT(RR)
          WRITE (6,145) PCENT,RR,R
          STOP
C
 145      FORMAT (1H /////5X,*STATISTICAL VALUES*//10X,*PERCENT SS =*,F1 .6/
         110X,*R-SQUARED  =*,F12.6/10X,*R           =*,F12.6)
 150      FORMAT (5X,*EST. H = A1 + A2(X) + A3(Y) + A4(X**2) + A5(X)(Y) + A6
         1(Y**2) +*/14X,*A7(X**3) + A8(X**2)(Y) + A9(X)(Y**2) + A10(Y**3) +*
         2/14X,*A11(X**4) + A12(X**3)(Y) + A13(X**2)(Y**2) +*/14X,*A14(X)(Y*
         3*3) + A15(Y**4) + A16(X**5) + A17(X**4)(Y) +*/14X,*A18(X**3)(Y**2)
         4 + A19(X**2)(Y**3) + A20(X)(Y**4) + A21(Y**5).*///5X,*I*,15X,*A1*/
         5)
 155      FORMAT (4X,I2,10X,F10.3)
 160      FORMAT (1H15X,*ORIGINAL AND COMPUTED VALUES*///)
 165      FORMAT (3F10.0)
 170      FORMAT (1H ,I4,5(4X,F7.3))
 175      FORMAT (1H1,*FIFTH ORDER POLYNOMIAL APPROXIMATION FOR FLOWNET--*//
         1/1X,*THE EQUATION HAS THE FOLLOWING FORM*//)
 180      FORMAT (1H ,*FLOWNET DATA MATRIX IS SINGULAR*)
 185      FORMAT (1H ,*PT.NO.*,5X,*X*,10X,*Y*,10X,*H*,7X,*EST. H*,5X,*RESIDU
         1AL*///)
 190      FORMAT (I3)
          END
```

STATEMENT NUMBER	DEFINITION		REFERENCES		
5	11.		10.		
10	13.		9.		
15	39.		37.	38.	
20	41.		40.		
25	43.		15.		
30	47.		44.	46.	
35	51.		56.		
40	53.		51.	52.	
45	55.		52.	54.	
50	57.		56.		
55	59.		54.		
60	61.		64.	67.	70.
65	63.		62.		
70	65.		63.	64.	
75	68.		67.		
80	71.		62.		
85	73.		72.		
90	77.		76.		
95	80.		79.		
100	82.		81.		
105	83.		48.	78.	79.
110	87.		85.	86.	
115	88.		86.		
120	90.		84.	88.	
125	94.		91.	93.	
130	98.		97.		
135	104.		101.		
140	110.		109.		
145	117.	FORMAT	115.		
150	118.	FORMAT	96.		
155	119.	FORMAT	98.		
160	120.	FORMAT	99.		
165	121.	FORMAT	16.		
170	122.	FORMAT	104.		
175	123.	FORMAT	95.		
180	124.	FORMAT	57.		
185	125.	FORMAT	100.		
190	126.	FORMAT	14.		

LABEL	TYPE	DEFINITION			REFERENCES						
A	R	4.	CDE		5.	92.	94.	98.	110.		
ABS	R	59.		FUNCTION	66.						
AM	R	2.	D		11.	39.	47.	54.	59.	66.	73.
					74.	75.	77.	80.	82.	90.	
AMA	R	59.			67.	68.					
AMB	R	66.			67.	68.					
BB	R	2.	D		13.	41.	94.	110.			
DA	R	75.			77.						
DB	R	80.			82.						
DELTA	R	103.			104.						
EST	R	102.			103.	104.					
FLOAT	R	105.		FUNCTION							
HEAD	R	102.		FUNCTION							
I	I	9.			10.	11.	12.	13.	37.	38.	39.
					40.	41.	44.	45.	47.	49.	52.
					54.	55.	56.	59.	60.	69.	71.
					74.	75.	77.	79.	82.	84.	86.
					90.	91.	92.	94.	97.	98.	101.
					102.	103.	04.	109.	110.		
II	I	60.			61.	62.	64.	66.	69.		
IP1	I	45.			46.						
IZ	I	63.			64.	72.	73.	76.	77.	78.	79.
					80.	82.					
J	I	10.			11.	38.	39.	40.	47.	48.	50.
					63.	71.	85.	86.	90.	93.	94.
JJ	I	50.			51.						
JZ	I	81.			82.						
L	I	15.			16.	17.	18.	19.	20.	21.	22.
					23.	24.	25.	26.	27.	29.	30.
					31.	32.	35.	36.	41.	42.	43.
					51.	52.	88.	89.	90.		
LL	I	89.			90.						
N	I	2.	D		12.	52.	64.	71.	86.	89.	
NTOT	I	14.			15.	101.	105.				
PAR	R	2.	DE		5.	8.	17.	18.	19.	20.	21.
					22.	23.	24.	25.	26.	27.	28.
					29.	30.	31.	32.	33.	34.	35.
					36.	39.	41.				
PCENT	R	113.			115.						
R	R	114.			115.						
RR	R	112.			113.	114.	115.				
SQRT	R	114.		FUNCTION							
SSR	R	108.			110.	111.	112.				
SSZ	R	6.			42.	107.	112.				
SSZBAR	R	106.			107.	111.					
X	R	3.	D		16.	17.	19.	20.	22.	24.	26.
					29.	31.	35.	102.	104.		
XINV	R	2.	D		90.	94.					
Y	R	3.	D		16.	18.	20.	21.	23.	25.	27.
					30.	32.	36.	102.	104.		
Z	R	3.	D		16.	41.	42.	43.	103.	104.	
ZBAR	R	105.			106.						
ZSUM	R	7.			43.	105.	106.				

FORSTAT Listing of Subroutine STORE1

```
 1.          SUBROUTINE STORE1 (XCEN,YCEN,R,FT)
       C     ------------------------------------------------------------------
       C                         SUBROUTINE STORE1
       C     ------------------------------------------------------------------
       C     PURPOSE-
       C          TO CALCULATE THE PROPERTIES OF A SLIP CIRCLE AND TO
       C     EVALUATE THE TAYLOR FACTOR OF SAFETY.
       C     ------------------------------------------------------------------
       C     USAGE-
       C          CALL STORE1(XCEN,YCEN,R,I)
       C
       C          WHERE  XCEN  = X-COORD. OF CIRCLE CENTER
       C                 YCEN  = Y-COORD. OF CIRCLE CENTER
       C                 R     = RADIUS OF CIRCLE
       C                 FT    = TAYLOR FACTOR OF SAFETY
       C
       C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON
       C     ------------------------------------------------------------------
       C     SUPPORTING ROUTINES-
       C          SUBROUTINE WEIGHT
       C          FUNCTION   HEAD
       C     ------------------------------------------------------------------
       C     SYSTEM ROUTINES-
       C          FUNCTION SIN
       C          FUNCTION COS
       C          FUNCTION ATAN
       C     ------------------------------------------------------------------
 2.          COMMON DUM1(25),DATUM,IDUM(17),NSUR,IWAT,NCONC,NUNIF
 3.          COMMON DUM2(135),XQL(5),XQR(5),XW(5),QU(5),ANGQU(5),QC(5),ANGQC(5)
 4.          COMMON C(15),PHI(15),XPIEZ(9),YPIEZ(9),Y1(10),XCHECK(25)
 5.          COMMON YCHECK(25),EXIT(2,2)
 6.          EQUIVALENCE (HT,HM), (ALPHA,THETA), (SLP,Y), (YAVEB,YAVET)
 7.          DATA AINT,UNITW/0.1,62.4/
 8.          L=1
 9.          IDIR=1
10.          RNUM=0.0
11.          DENUM=0.0
12.          XL=EXIT(1,1)
13.          YL=EXIT(1,2)
14.          Y1(1)=YL
15.          Y1(2)=YL
16.    5     IF (XCHECK(L)-EXIT(1,1)) 10,10,15
17.    10    L=L+1
18.          GO TO 5
       C
       C     ------------------------------------
       C     DETERMINE SLICES, MOVING IN +X DIRECTION
       C     ------------------------------------
19.    15    ALPHA=ATAN((XL-XCEN)/(YCEN-YL))
20.          YR=YL+R*(COS(ALPHA)-COS(ALPHA+AINT))
21.          IF (YR-EXIT(2,2)) 20,50,50
22.    20    XR=XL+R*(SIN(ALPHA+AINT)-SIN(ALPHA))
23.    25    IF (XR-XCHECK(L)) 60,30,40
24.    30    L=L+1
25.          GO TO 25
       C
26.    35    L=L+1
27.    40    IF (XCHECK(L+1)-XCHECK(L)) 45,35,45
28.    45    XR=XCHECK(L)
29.          YR=YCHECK(L)
30.          L=L+1
31.          GO TO 60
       C
32.    50    IF (EXIT(2,1)-XCHECK(L)) 55,55,40
33.    55    XR=EXIT(2,1)
34.          YR=EXIT(2,2)
35.          IDIR=2
```

```
      C     ------------------------------------------
      C     STORE INFORMATION ON CURRENT SLICE
      C     ------------------------------------------
       60   THICK=XR-XL
            TNP=(YR-YL)/THICK
            CALL WEIGHT (XR,YR,TNP,YYL,K,WSLC)
            WSLC=WSLC*THICK
            THETA=ATAN(TNP)
            SN=SIN(THETA)
            CS=COS(THETA)
            YAVET=(YYL+YI(1))/2.
            YBAR=(YCEN-YAVET)/R
            XAVE=(XR+XL)/2.
            ALP=(YI(1)-YTL)/THICK
            RNUM=RNUM+C(K)*THICK/CS
            PNORM=WSLC*CS
            DENOM=DENOM+WSLC*SN
      C     ------------------------------------------
      C     CHECK FOR CONCENTRATED LOADING
      C     ------------------------------------------
            IF (NCONC) 85,85,65
       65   DO 80 J=1,NCONC
               IF (XQ(J)-XL) 80,80,70
       70      IF (XQ(J)-XR) 75,80,80
       75      DENOM=DENOM+SN*QC(J)*SIN(ANGQC(J))+QC(J)*YBAR*COS(ANGQC(J))
               PNORM=PNORM+QC(J)*SIN(ANGQC(J)-THETA)
               GO TO 85
      C
       80   CONTINUE
      C     ------------------------------------------
      C     CHECK FOR UNIFORM LOADING
      C     ------------------------------------------
       85   IF (NUNIF) 110,110,90
       90   DO 105 J=1,NUNIF
               IF (XAVE-XQL(J)) 105,105,95
       95      IF (XAVE-XQR(J)) 100,105,105
      100      SLP=QU(J)*THICK/COS(ATAN(ALP))
               DENOM=DENOM+SLP*(COS(ANGQU(J))*YBAR+SN*SIN(ANGQU(J)))
               PNORM=PNORM+SLP*SIN(ANGQU(J)-THETA)
               GO TO 110
      C
      105   CONTINUE
      C     ------------------------------------------
      C     CHECK FOR G.W.T. CONDITION
      C     ------------------------------------------
      110   IF (IWAT) 170,170,115
      115   DO 125 J=2,NSUR
               IF (XAVE-XPIEZ(J-1)) 125,125,120
      120      IF (XAVE-XPIEZ(J)) 130,125,125
      125   CONTINUE
            GO TO 170
      C
      130   SLP=(YPIEZ(J)-YPIEZ(J-1))/(XPIEZ(J)-XPIEZ(J-1))
            Y=YPIEZ(J-1)+SLP*(XAVE-XPIEZ(J-1))
            GW=UNITW*THICK
            HT=Y-YAVET
            IF (HT) 150,150,135
      135   GO TO (145,140), IWAT
      140   HT=HEAD(XAVE,YAVET)-YAVET+DATUM
      145   DENOM=DENOM+GW*HT*(SN-YBAR*ALP)
            PNORM=PNORM+GW*HT*(CS+SN*ALP)
      150   YAVEB=(YR+YL)/2.
            HB=Y-YAVEB
            IF (HB) 170,170,155
      155   GO TO (165,160), IWAT
      160   HB=HEAD(XAVE,YAVEB)-YAVEB+DATUM
      165   PNORM=PNORM-GW*HB/CS
      170   RNUM=RNUM+PNORM*PHI(K)
            XL=XR
            YL=YR
      C     ------------------------------------------
      C     RETURN TO START OF SUBROUTINE TO PROCESS ANOTHER SLICE IF NECESSARY
      C     ------------------------------------------
            GO TO (15,175), IDIR
      175   FT=RNUM/DENOM
            RETURN
            END
```

STATEMFNT NUMBER	DEFINITION	REFERENCES		
5	16.	18.		
10	17.	16.		
15	19.	16.	91.	
20	22.	21.		
25	23.	25.		
30	24.	23.		
35	26.	27.		
40	27.	23.	32.	
45	28.	27.		
50	32.	21.		
55	33.	32.		
60	36.	23.	31.	
65	51.	50.		
70	53.	52.		
75	54.	53.		
80	57.	51.	52.	53.
85	58.	50.	56.	
90	59.	58.		
95	61.	60.		
100	62.	61.		
105	66.	59.	60.	61.
110	67.	58.	65.	
115	68.	67.		
120	70.	69.		
125	71.	68.	69.	70.
130	73.	70.		
135	78.	77.		
140	79.	78.		
145	80.	78.		
150	82.	77.		
155	85.	84.		
160	86.	85.		
165	87.	85.		
170	88.	67.	72.	84.
175	92.	91.		

LABEL	TYPE	DEFINITION		REFERENCES						
AINT	R	7.	DATA	20.	22.					
ALP	R	66.		62.	80.	81.				
ALPHA	R	6. E		19.	20.	22.				
ANGOC	R	3. CD		54.	55.					
ANGQU	R	3. CD		63.	64.					
ATAN	R	19.	FUNCTION	40.	62.					
C	R	4. CD		47.						
COS	R	20.	FUNCTION	42.	56.	62.	63.			
CS	R	42.		47.	48.	81.	87.			
DATUM	R	2. C		79.	86.					
DENOM	R	11.		49.	54.	63.	80.	92.		
DUM1	R	2. CD								
DUM2	R	3. CD								
EXIT	R	5. CD		12.	13.	16.	21.	32.	33.	34.
FT	R	1.		92.						
GW	R	75.		80.	81.	87.				
HB	R	6. E		83.	84.	86.	87.			
HEAD	R	79.	FUNCTION	86.						
HT	R	6. E		76.	77.	79.	80.	81.		
IDIR	I	9.		35.	91.					
IDUM	I	2. CD								
IWAT	I	2. C		67.	78.	85.				
J	I	51.		52.	53.	54.	55.	59.	60.	61.
				62.	63.	64.	68.	69.	70.	73.
				74.						
K	I	38.		47.	88.					
L	I	8.		16.	17.	23.	24.	26.	27.	28.
				29.	30.	32.				
NCONC	I	2. C		50.	51.					
NSUR	I	2. C		68.						
NUNIF	I	2. C		58.	59.					
PHI	R	4. CD		88.						
PNORM	R	48.		55.	64.	81.	87.	88.		
QC	R	3. CD		54.	55.					
QU	R	3. CD		62.						
R	R	1.		20.	22.	44.				
RNUM	R	10.		47.	88.	92.				
SIN	R	22.	FUNCTION	41.	54.	55.	63.	64.		
SLP	R	6. E		62.	63.	64.	73.	74.		
SN	R	41.		49.	54.	63.	80.	81.		
THETA	R	6. E		40.	41.	42.	55.	64.		
THICK	R	36.		37.	39.	46.	47.	62.	75.	
TNP	R	37.		38.	40.					
UNITW	R	7.	DATA	75.						
WEIGHT	R	38.	SUBROUTINE							
WSLC	R	38.		39.	48.	49.				
XAVE	R	45.		60.	61.	69.	70.	74.	79.	86.
XCEN	R	1.		19.						
XCHECK	R	4. CD		16.	23.	27.	28.	32.		
XL	R	12.		19.	22.	36.	45.	52.	89.	
XPIEZ	R	4. CD		69.	70.	73.	74.			
XQ	R	3. CD		52.	53.					
XQL	R	3. CD		60.						
XQR	R	3. CD		61.						
XR	R	22.		23.	28.	33.	36.	38.	45.	53.
				89.						
Y	R	6. E		74.	76.	83.				
YAVER	R	6. E		82.	83.	86.				
YAVET	R	6. E		43.	44.	76.	79.			
YBAR	R	44.		54.	63.	80.				
YCEN	R	1.		19.	44.					
YCHECK	R	5. CD		29.						
YL	R	13.		14.	15.	19.	20.	37.	82.	90.
YPIEZ	R	4. CD		73.	74.					
YR	R	20.		21.	29.	34.	37.	38.	82.	90.
YTL	R	38.		43.	46.					
Y1	R	4. CD		14.	15.	43.	46.			

FORSTAT Listing of Subroutine STORE2

```
      SUBROUTINE STORE2 (XCEN,YCEN,R,I)                                 ST2    2
C     ------------------------------------------------------------------ST2    4
C                               SUBROUTINE STORE2                       ST2    6
C     ------------------------------------------------------------------ST2    8
C     PURPOSE-                                                          ST2   10
C          TO CALCULATE AND STORE IN COMMON THE PROPERTIES OF A SLIP    ST2   12
C     CIRCLE  NEEDED  TO  EVALUATE THE MODIFIED BISHOP FACTOR OF SAFETY. ST2  14
C     (MOMENT CENTER = CIRCLE CENTER)                                   ST2   16
C     ------------------------------------------------------------------ST2   18
C     USAGE-                                                            ST2   20
C          CALL STORE1(XCEN,YCEN,R,I)                                   ST2   22
C                                                                       ST2   24
C          WHERE  XCEN  = X-COORD. OF CIRCLE CENTER                     ST2   26
C                 YCEN  = Y-COORD. OF CIRCLE CENTER                     ST2   28
C                 R     = RADIUS OF CIRCLE                              ST2   30
C                 I     = NUMBER OF SLICES GENERATED                    ST2   32
C                                                                       ST2   34
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON         ST2   36
C     ------------------------------------------------------------------ST2   38
C     SUPPORTING ROUTINES-                                              ST2   40
C          SUBROUTINE WEIGHT                                            ST2   42
C          FUNCTION   HEAD                                              ST2   44
C     ------------------------------------------------------------------ST2   46
C     SYSTEM ROUTINES-                                                  ST2   48
C          FUNCTION SIN                                                 ST2   50
C          FUNCTION COS                                                 ST2   52
C          FUNCTION ATAN                                                ST2   54
C     ------------------------------------------------------------------ST2   56
      COMMON DUM1(25),DATUM,IDUM(17),NSUR,IWAT,NCONC,NUNIF              ST2   58
      COMMON DUM2(135),XQL(5),XQR(5),XQ(5),QU(5),ANGQU(5),QC(5),ANGQC(5)ST2   60
      COMMON C(15),PHI(15),XPIEZ(9),YPIEZ(9),Y1(10),XCHECK(25)          ST2   62
      COMMON YCHECK(25),EXIT(2,2),TOP1(50),TOP2(50),TOP3(50)            ST2   64
      EQUIVALENCE (HT,HU), (ALPHA,THETA), (SLP,Y)                       ST2   66
      DATA AINT,UNITW/0.1,62.4/                                         ST2   68
      I=0                                                               ST2   70
      L=1                                                               ST2   72
      IDIR=1                                                            ST2   74
      XL=EXIT(1,1)                                                      ST2   76
      YL=EXIT(1,2)                                                      ST2   78
      Y1(1)=YL                                                          ST2   80
      Y1(2)=YL                                                          ST2   82
    5 IF (XCHECK(L)-EXIT(1,1)) 10,10,15                                 ST2   84
   10 L=L+1                                                             ST2   86
      GO TO 5                                                           ST2   88
C                                                                       ST2   90
C     ---------------------------------------                           ST2   92
C     DETERMINE SLICES, MOVING IN +X DIRECTION                          ST2   94
C     ---------------------------------------                           ST2   96
   15 ALPHA=ATAN((XL-XCEN)/(YCEN-YL))                                   ST2   98
      YR=YL+R*(COS(ALPHA)-COS(ALPHA+AINT))                              ST2  100
      IF (YR-EXIT(2,2)) 20,50,50                                        ST2  102
   20 XR=XL+R*(SIN(ALPHA+AINT)-SIN(ALPHA))                              ST2  104
   25 IF (XR-XCHECK(L)) 60,30,40                                        ST2  106
   30 L=L+1                                                             ST2  108
      GO TO 25                                                          ST2  110
C                                                                       ST2  112
   35 L=L+1                                                             ST2  114
   40 IF (XCHECK(L+1)-XCHECK(L)) 45,35,45                               ST2  116
   45 XR=XCHECK(L)                                                      ST2  118
      YR=YCHECK(L)                                                      ST2  120
      L=L+1                                                             ST2  122
      GO TO 60                                                          ST2  124
C                                                                       ST2  126
   50 IF (EXIT(2,1)-XCHECK(L)) 55,55,40                                 ST2  128
   55 XR=EXIT(2,1)                                                      ST2  130
      YR=EXIT(2,2)                                                      ST2  132
      IDIR=2                                                            ST2  134
   60 I=I+1                                                             ST2  136
```

```
C     ------------------------------------------------
C     STORE INFORMATION ON CURRENT SLICE
C     ------------------------------------------------
        THICK=XR-XL
        TNP=(YR-YL)/THICK
        CALL WEIGHT (XR,YR,TNP,YTL,K,WSLC)
        WSLC=WSLC*THICK
        THETA=ATAN(TNP)
        SN=SIN(THETA)
        CS=COS(THETA)
        YAVET=(YTL+YI(I))/2.
        YAVEB=(YR+YL)/2.
        YBAR=YCEN-YAVEB
        HYBR=1.-(YAVET-YAVEB)/YBAR
        XAVE=(XR+XL)/2.
        ALP=(YI(I)-YTL)/THICK
        TOP1(I)=C(K)*THICK/(CS*CS)
        TOP2(I)=WSLC*TNP
        TOP3(I)=TNP*PHI(K)
        PNORM=WSLC
C     ------------------------------------------------
C     CHECK FOR CONCENTRATED LOADING
C     ------------------------------------------------
        IF (NCONC) 85,85,65
 65     DO 80 J=1,NCONC
           IF (XQ(J)-XL) 80,80,70
 70        IF (XQ(J)-XR) 75,80,80
 75        PNORM=PNORM+QC(J)*(SIN(ANGQC(J))-HYBR*COS(ANGQC(J))*TNP)
           TOP2(I)=TOP2(I)+QC(J)*(TNP*SIN(ANGQC(J))+HYBR*COS(ANGQC(J)))
           GO TO 85
C
 80     CONTINUE
C     ------------------------------------------------
C     CHECK FOR UNIFORM LOADING
C     ------------------------------------------------
 85     IF (NUNIF) 110,110,90
 90     DO 105 J=1,NUNIF
           IF (XAVE-XQL(J)) 105,105,95
 95        IF (XAVE-XQR(J)) 100,105,105
 100       SLP=QU(J)*THICK/COS(ATAN(ALP))
           TOP2(I)=TOP2(I)+SLP*(TNP*SIN(ANGQU(J))+HYBR*COS(ANGQU(J)))
           PNORM=PNORM+SLP*(SIN(ANGQU(J))-HYBR*COS(ANGQU(J))*TNP)
           GO TO 110
C
 105    CONTINUE
C     ------------------------------------------------
C     CHECK FOR G.W.T. CONDITION
C     ------------------------------------------------
 110    IF (IWAT) 170,170,115
 115    DO 125 J=2,NSUR
           IF (XAVE-XPIEZ(J-1)) 125,120,120
 120       IF (XAVE-XPIEZ(J)) 130,125,125
 125    CONTINUE
        GO TO 170
C
 130    SLP=(YPIEZ(J)-YPIEZ(J-1))/(XPIEZ(J)-XPIEZ(J-1))
        Y=YPIEZ(J-1)+SLP*(XAVE-XPIEZ(J-1))
        GW=UNITW*THICK
        HT=Y-YAVET
        IF (HT) 150,150,135
 135    GO TO (145,140), IWAT
 140    HT=HEAD(XAVE,YAVET)-YAVET+DATUM
 145    PNORM=PNORM+GW*HT*(1.+HYBR*ALP*TNP)
        TOP2(I)=TOP2(I)+GW*HT*(TNP-HYBR*ALP)
 150    HB=Y-YAVEB
        IF (HB) 170,170,155
 155    GO TO (165,160), IWAT
 160    HB=HEAD(XAVE,YAVEB)-YAVEB+DATUM
 165    PNORM=PNORM-GW*HB/(CS*CS)
 170    TOP1(I)=(TOP1(I)+PHI(K)*PNORM)*YBAR
        TOP2(I)=TOP2(I)*YBAR
        XL=XR
        YL=YR
C     ------------------------------------------------
C     RETURN TO START OF SUBROUTINE TO PROCESS ANOTHER SLICE IF NECESSARY
C     ------------------------------------------------
        GO TO (15,175), IDIR
 175    RETURN
        END
```

STATEMENT NUMBER	DEFINITION	REFERENCES		
5	15.	17.		
10	16.	15.		
15	18.	15.	94.	
20	21.	20.		
25	22.	24.		
30	23.	22.		
35	25.	26.		
40	26.	22.	31.	
45	27.	26.		
50	31.	20.		
55	32.	31.		
60	35.	22.	30.	
65	54.	53.		
70	56.	55.		
75	57.	56.		
80	60.	54.	55.	56.
85	61.	53.	59.	
90	62.	61.		
95	64.	63.		
100	65.	64.		
105	69.	62.	63.	64.
110	70.	61.	68.	
115	71.	70.		
120	73.	72.		
125	74.	71.	72.	73.
130	76.	73.		
135	81.	80.		
140	82.	81.		
145	83.	81.		
150	85.	80.		
155	87.	86.		
160	88.	87.		
165	89.	87.		
170	90.	70.	75.	86.
175	95.	94.		

LABEL	TYPE	DEFINITION		REFERENCES
AINT	R	7.	DATA	19. 21.
ALP	R	48.		65. 83. 84.
ALPHA	R	6. E		18. 19. 21.
ANGQC	R	3. CD		57. 58.
ANGQU	R	3. CD		66. 67.
ATAN	R	18.	FUNCTION	40. 65.
C	R	4. CD		49.
COS	R	19.	FUNCTION	42. 57. 58. 65. 66. 67.
CS	R	42.		49. 89.
DATUM	R	2. C		82. 88.
DUM1	R	2. CD		
DUM2	R	3. CD		
EXIT	R	5. CD		11. 12. 15. 20. 31. 32. 33.
GW	R	78.		83. 84. 89.
HB	R	6. E		85. 86. 88. 89.
HEAD	R	82.	FUNCTION	88.
HT	R	6. E		79. 80. 82. 83. 84.
HYHR	R	46.		57. 58. 66. 67. 83. 84.
I	I	1.		8. 35. 35. 49. 50. 51. 58.
				66. 84. 90. 91.
IDIR	I	10.		34. 94.
IDUM	I	2. CD		
IWAT	I	2. C		70. 81. 87.
J	I	54.		55. 56. 57. 58. 62. 63. 64.
				65. 66. 67. 71. 72. 73. 76.
				77.
K	I	38.		49. 51. 90.
L	I	9.		15. 16. 22. 23. 25. 26. 27.
				28. 29. 31.
NCONC	I	2. C		53. 54.
NSUR	I	2. C		71.
NUNIF	I	2. C		61. 62.
PHI	R	4. CD		51. 90.
PNORM	R	52.		57. 67. 83. 89. 90.
QC	R	3. CD		57. 58.
QU	R	3. CD		65.
R	R	1.		19. 21.
SIN	R	21.	FUNCTION	41. 57. 58. 66. 67.
SLP	R	6. E		65. 66. 67. 76. 77.
SN	R	41.		
THETA	R	6. E		40. 41. 42.
THICK	R	36.		37. 39. 48. 49. 65. 78.
TNP	R	37.		38. 40. 50. 51. 57. 58. 66.
				67. 83. 84.
TOP1	R	5. CD		49. 90.
TOP2	R	5. CD		50. 58. 66. 84. 91.
TOP3	R	5. CD		51.
UNITW	R	7.	DATA	78.
WEIGHT	R	38.	SUBROUTINE	
WSLC	R	38.		39. 50. 52.
XAVE	R	47.		63. 64. 72. 73. 77. 82. 88.
XCEN	R	1.		18.
XCHECK	R	4. CD		15. 22. 26. 27. 31.
XL	R	11.		18. 21. 36. 47. 55. 92.
XPIEZ	R	4. CD		72. 73. 76. 77.
XG	R	3. CD		55. 56.
XQL	R	3. CD		63.
XQR	R	3. CD		64.
XR	R	21.		22. 27. 32. 36. 38. 47. 56.
				92.
Y	R	6. E		77. 79. 85.
YAVEH	R	44.		45. 46. 85. 88.
YAVET	R	43.		46. 79. 82.
YBAR	R	45.		46. 90. 91.
YCEN	R	1.		18. 45.
YCHECK	R	5. CD		28.
YL	R	12.		13. 14. 18. 19. 37. 44. 93.
YPIEZ	R	4. CD		76. 77.
YR	R	19.		20. 28. 33. 37. 38. 44. 93.
YTL	R	38.		43. 48.
Y1	R	4. CD		13. 14. 43. 48.

FORSTAT Listing of Subroutine STORE3

```
      SUBROUTINE STORE3 (XCEN,YCEN,R,I)                                 ST3   2
C     ------------------------------------------------------------------ST3   4
C                                SUBROUTINE STORE3                      ST3   6
C     ------------------------------------------------------------------ST3   8
C     PURPOSE-                                                          ST3  10
C          TO CALCULATE AND STORE IN COMMON THE PROPERTIES OF A SLIP    ST3  12
C     CIRCLE  NEEDED  TO  EVALUATE THE ADJUSTED MODIFIED BISHOP FACTOR OF ST3  14
C     SAFETY.  (MOMENT CENTER = +Y INFINITY)                            ST3  16
C     ------------------------------------------------------------------ST3  18
C     USAGE-                                                            ST3  20
C          CALL STORE1(XCEN,YCEN,R,I)                                   ST3  22
C                                                                       ST3  24
C          WHERE  XCEN   = X-COORD. OF CIRCLE CENTER                    ST3  26
C                 YCEN   = Y-COORD. OF CIRCLE CENTER                    ST3  28
C                 R      = RADIUS OF CIRCLE                             ST3  30
C                 I      = NUMBER OF SLICES GENERATED                   ST3  32
C                                                                       ST3  34
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON        ST3  36
C     ------------------------------------------------------------------ST3  38
C     SUPPORTING ROUTINES-                                              ST3  40
C          SUBROUTINE WEIGHT                                            ST3  42
C          FUNCTION   HEAD                                              ST3  44
C     ------------------------------------------------------------------ST3  46
C     SYSTEM ROUTINES-                                                  ST3  48
C          FUNCTION SIN                                                 ST3  50
C          FUNCTION COS                                                 ST3  52
C          FUNCTION ATAN                                                ST3  54
C     ------------------------------------------------------------------ST3  56
      COMMON DUM1(25),DATUM,IDUM(17),NSUP,IWAT,NCONC,NUNIF              ST3  58
      COMMON DUM2(135),XQL(5),XQR(5),XQ(5),QU(5),ANGQU(5),QC(5),ANGQC(5)ST3  60
      COMMON C(15),PHI(15),XPIEZ(9),YPIEZ(9),YI(10),XCHECK(25)          ST3  62
      COMMON YCHECK(25),EXIT(2,2),TOP1(50),TOP2(50),TOP3(50)            ST3  64
      EQUIVALENCE (HT,HB), (ALPHA,THETA), (SLP,Y), (YAVET,YAVEB)        ST3  66
      DATA AINT,UNITW/0.1,62.4/                                         ST3  68
      I=0                                                               ST3  70
      L=1                                                               ST3  72
      IDIR=1                                                            ST3  74
      XL=EXIT(1,1)                                                      ST3  76
      YL=EXIT(1,2)                                                      ST3  78
      YI(1)=YL                                                          ST3  80
      YI(2)=YL                                                          ST3  82
    5 IF (XCHECK(L)-EXIT(1,1)) 10,10,15                                 ST3  84
   10 L=L+1                                                             ST3  86
      GO TO 5                                                           ST3  88
C                                                                       ST3  90
C     ---------------------------------                                 ST3  92
C     DETERMINE SLICES, MOVING IN +X DIRECTION                          ST3  94
C     ---------------------------------                                 ST3  96
   15 ALPHA=ATAN((XL-XCEN)/(YCEN-YL))                                   ST3  98
      YR=YL+R*(COS(ALPHA)-COS(ALPHA+AINT))                              ST3 100
      IF (YR-EXIT(2,2)) 20,50,50                                        ST3 102
   20 XR=XL+R*(SIN(ALPHA+AINT)-SIN(ALPHA))                              ST3 104
   25 IF (XR-XCHECK(L)) 60,30,40                                        ST3 106
   30 L=L+1                                                             ST3 108
      GO TO 25                                                          ST3 110
C                                                                       ST3 112
   35 L=L+1                                                             ST3 114
   40 IF (XCHECK(L+1)-XCHECK(L)) 45,35,45                               ST3 116
   45 XR=XCHECK(L)                                                      ST3 118
      YR=YCHECK(L)                                                      ST3 120
      L=L+1                                                             ST3 122
      GO TO 60                                                          ST3 124
C                                                                       ST3 126
   50 IF (EXIT(2,1)-XCHECK(L)) 55,55,40                                 ST3 128
   55 XR=EXIT(2,1)                                                      ST3 130
      YR=EXIT(2,2)                                                      ST3 132
      IDIR=2                                                            ST3 134
   60 I=I+1                                                             ST3 136
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C     -----------------------------------             ST3 138
C     STORE INFORMATION ON CURRENT SLICE              ST3 140
C     -----------------------------------             ST3 142
      THICK=XR-XL                                     ST3 144
      TNP=(YR-YL)/THICK                               ST3 146
      CALL WEIGHT (XR,YR,TNP,YTL,K,WSLC)              ST3 148
      WSLC=WSLC*THICK                                 ST3 150
      THETA=ATAN(TNP)                                 ST3 152
      SN=SIN(THETA)                                   ST3 154
      CS=COS(THETA)                                   ST3 156
      XAVE=(XR+XL)/2.                                 ST3 158
      ALP=(YI(I)-YTL)/THICK                           ST3 160
      TOP1(I)=C(K)*THICK/(CS*CS)                      ST3 162
      TOP2(I)=WSLC*TNP                                ST3 164
      TOP3(I)=TNP*PHI(K)                              ST3 166
      PNORM=WSLC                                      ST3 168
C     -----------------------------------             ST3 170
C     CHECK FOR CONCENTRATED LOADING                  ST3 172
C     -----------------------------------             ST3 174
      IF (NCONC) 85,85,65                             ST3 176
   65 DO 80 J=1,NCONC                                 ST3 178
         IF (XQ(J)-XL) 80,80,70                       ST3 180
   70    IF (XQ(J)-XR) 75,80,80                       ST3 182
   75    PNORM=PNORM+QC(J)*(SIN(ANGQC(J))-COS(ANGQC(J))*TNP)       ST3 184
         TOP2(I)=TOP2(I)+QC(J)*(TNP*SIN(ANGQC(J))+COS(ANGQC(J)))   ST3 186
         GO TO 85                                     ST3 188
C                                                     ST3 190
   80 CONTINUE                                        ST3 192
C     -----------------------------------             ST3 194
C     CHECK FOR UNIFORM LOADING                       ST3 196
C     -----------------------------------             ST3 198
   85 IF (NUNIF) 110,110,90                           ST3 200
   90 DO 105 J=1,NUNIF                                ST3 202
         IF (XAVE-XQL(J)) 105,105,95                  ST3 204
   95    IF (XAVE-XQR(J)) 100,105,105                 ST3 206
  100    SLP=QU(J)*THICK/COS(ATAN(ALP))               ST3 208
         TOP2(I)=TOP2(I)+SLP*(TNP*SIN(ANGQU(J))+COS(ANGQU(J)))     ST3 210
         PNORM=PNORM+SLP*(SIN(ANGQU(J))-COS(ANGQU(J))*TNP)         ST3 212
         GO TO 110                                    ST3 214
C                                                     ST3 216
  105 CONTINUE                                        ST3 218
C     -----------------------------------             ST3 220
C     CHECK FOR G.W.T. CONDITION                      ST3 222
C     -----------------------------------             ST3 224
  110 IF (IWAT) 170,170,115                           ST3 226
  115 DO 125 J=2,NSUR                                 ST3 228
         IF (XAVE-XPIEZ(J-1)) 125,120,120             ST3 230
  120    IF (XAVE-XPIEZ(J)) 130,125,125               ST3 232
  125 CONTINUE                                        ST3 234
      GO TO 170                                       ST3 236
C                                                     ST3 238
  130 SLP=(YPIEZ(J)-YPIEZ(J-1))/(XPIEZ(J)-XPIEZ(J-1)) ST3 240
      Y=YPIEZ(J-1)+SLP*(XAVE-XPIEZ(J-1))              ST3 242
      YAVET=(YTL+YI(I))/2.                            ST3 244
      GW=UNITW*THICK                                  ST3 246
      HT=Y-YAVET                                      ST3 248
      IF (HT) 150,150,135                             ST3 250
  135 GO TO (145,140), IWAT                           ST3 252
  140 HT=HEAD(XAVE,YAVET)-YAVET+DATUM                 ST3 254
  145 PNORM=PNORM+GW*HT*(1.+ALP*TNP)                  ST3 256
      TOP2(I)=TOP2(I)+GW*HT*(TNP-ALP)                 ST3 258
  150 YAVER=(YR+YL)/2.                                ST3 260
      HB=Y-YAVER                                      ST3 262
      IF (HB) 170,170,155                             ST3 264
  155 GO TO (165,160), IWAT                           ST3 266
  160 HB=HEAD(XAVE,YAVER)-YAVER+DATUM                 ST3 268
  165 PNORM=PNORM-GW*HB/(CS*CS)                       ST3 270
  170 TOP1(I)=TOP1(I)+PHI(K)*PNORM                    ST3 272
      XL=XR                                           ST3 274
      YL=YR                                           ST3 276
C     -----------------------------------             ST3 278
C     RETURN TO START OF SUBROUTINE TO PROCESS ANOTHER SLICE IF NECESSARY ST3 280
C     -----------------------------------             ST3 282
      GO TO (10,175), IOTR                            ST3 284
  175 RETURN                                          ST3 286
      END                                             ST3 288-
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STATEMENT NUMBER	DEFINITION	REFERENCES		
5	15.	17.		
10	16.	15.		
15	18.	15.	91.	
20	21.	20.		
25	22.	24.		
30	23.	22.		
35	25.	26.		
40	26.	22.	31.	
45	27.	26.		
50	31.	20.		
55	32.	31.		
60	35.	22.	30.	
65	50.	49.		
70	52.	51.		
75	53.	52.		
80	56.	50.	51.	52.
85	57.	49.	55.	
90	58.	57.		
95	60.	59.		
100	61.	60.		
105	65.	58.	59.	60.
110	66.	57.	64.	
115	67.	66.		
120	69.	68.		
125	70.	67.	68.	69.
130	72.	69.		
135	78.	77.		
140	79.	78.		
145	80.	78.		
150	82.	77.		
155	85.	84.		
160	86.	85.		
165	87.	85.		
170	88.	66.	71.	84.
175	92.	91.		

LABEL	TYPE	DEFINITION		REFERENCES						
AINT	R	7.	DATA	19.	21.					
ALP	R	44.		61.	80.	81.				
ALPHA	R	6. E		18.	19.	21.				
ANGQC	R	3. CD		53.	54.					
ANGQU	R	3. CD		62.	63.					
ATAN	R	18.	FUNCTION	40.	61.					
C	R	4. CD		45.						
COS	R	19.	FUNCTION	42.	53.	54.	61.	62.	63.	
CS	R	42.		45.	87.					
DATUM	R	2. C		79.	86.					
DUM1	R	2. CD								
DUM2	R	3. CD								
EXIT	R	5. CD		11.	12.	15.	20.	31.	32.	33.
GW	R	75.		80.	81.	87.				
HB	R	6. E		83.	84.	86.	87.			
HEAD	R	79.	FUNCTION	86.						
HT	R	6. E		76.	77.	79.	80.	81.		
I	I	1.		8.	35.	35.	45.	46.	47.	54.
				62.	81.	88.				
IDIR	I	10.		34.	91.					
IDUM	I	2. CD								
IWAT	I	2. C		66.	78.	85.				
J	I	50.		51.	52.	53.	54.	58.	59.	60.
				61.	62.	63.	67.	68.	69.	72.
				73.						
K	I	38.		45.	47.	88.				
L	I	9.		15.	16.	22.	23.	25.	26.	27.
				28.	29.	31.				
NCONC	I	2. C		49.	50.					
NSUR	I	2. C		67.						
NUNIF	I	2. C		57.	58.					
PHI	R	4. CD		47.	88.					
PNORM	R	48.		53.	63.	80.	87.	88.		
QC	R	3. CD		53.	54.					
QU	R	3. CD		61.						
R	R	1.		19.	21.					
SIN	R	21.	FUNCTION	41.	53.	54.	62.	63.		
SLP	R	6. E		61.	62.	63.	72.	73.		
SN	R	41.								
THETA	R	6. E		40.	41.	42.				
THICK	R	36.		37.	39.	44.	45.	61.	75.	
TNP	R	37.		38.	40.	46.	47.	53.	54.	62.
				63.	80.	81.				
TOP1	R	5. CD		45.	88.					
TOP2	R	5. CD		46.	54.	62.	81.			
TOP3	R	5. CD		47.						
UNITW	R	7.	DATA	75.						
WEIGHT	R	38.	SUBROUTINE							
WSLC	R	38.		39.	46.	48.				
XAVE	R	43.		59.	60.	68.	69.	73.	79.	86.
XCEN	R	1.		18.						
XCHECK	R	4. CD		15.	22.	26.	27.	31.		
XL	R	11.		18.	21.	36.	43.	51.	89.	
XPIEZ	R	4. CD		68.	69.	72.	73.			
XQ	R	3. CD		51.	52.					
XQL	R	3. CD		59.						
XQR	R	3. CD		60.						
XR	R	21.		22.	27.	32.	36.	38.	43.	52.
				89.						
Y	R	6. E		73.	76.	83.				
YAVEB	R	6. E		82.	83.	86.				
YAVET	R	6. E		74.	76.	79.				
YCEN	R	1.		18.						
YCHECK	R	5. CD		28.						
YL	R	12.		13.	14.	18.	19.	37.	82.	90.
YPIEZ	R	4. CD		72.	73.					
YR	R	19.		20.	28.	33.	37.	38.	82.	90.
YTL	R	38.		44.	74.					
Y1	R	4. CD		13.	14.	44.	74.			

FORSTAT Listing of Subroutine STORE4

```
      SUBROUTINE STORE4 (NSLICE,ILOW,NUMXY)                             ST4    2
C     ------------------------------------------------------------------ST4    4
C                             SUBROUTINE STORE4                          ST4    6
C     ------------------------------------------------------------------ST4    8
C     PURPOSE-                                                           ST4   10
C          TO CALCULATE AND STORE IN COMMON THE PROPERTIES OF AN         ST4   12
C     IRREGULAR SLIP SURFACE NEEDED TO EVALUATE THE ADJUSTED MODIFIED    ST4   14
C     BISHOP FACTOR OF SAFETY. (MOMENT CENTER = +Y INFINITY)             ST4   16
C     ------------------------------------------------------------------ST4   18
C     USAGE-                                                             ST4   20
C          CALL STORE4(NSLICE,ILOW,NUMXY)                                ST4   22
C                                                                        ST4   24
C          WHERE  NSLICE = NUMBER OF SLICES GENERATED                    ST4   26
C                 ILOW   = SUBSCRIPT OF 2ND COORD POINT OF SLIP SURFACE  ST4   28
C                 NUMXY  = SUBSCRIPT OF LAST COORD POINT OF SLIP SURFACE ST4   30
C                                                                        ST4   32
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON          ST4   34
C     ------------------------------------------------------------------ST4   36
C     SUPPORTING ROUTINES-                                               ST4   38
C          SUBROUTINE WEIGHT                                             ST4   40
C          FUNCTION   HEAD                                               ST4   42
C     ------------------------------------------------------------------ST4   44
C     SYSTEM ROUTINES-                                                   ST4   46
C          FUNCTION SIN                                                  ST4   48
C          FUNCTION COS                                                  ST4   50
C          FUNCTION ATAN                                                 ST4   52
C     ------------------------------------------------------------------ST4   54
      COMMON DUM1(25),DATUM,IDUM(17),NSUR,IWAT,NCONC,NUNIF,DUM2(135)     ST4   56
      COMMON XQL(5),XQR(5),XQ(5),QU(5),ANGQU(5),QC(5),ANGQC(5),C(15)     ST4   58
      COMMON PHI(15),XPIEZ(9),YPIEZ(9),Y1(10),XCHECK(25),YCHECK(25)      ST4   60
      COMMON DUM3(4),TOP1(50),TOP2(50),TOP3(50),XBL(12),YBL(12),SQ(11,2) ST4   62
      EQUIVALENCE (HT,HB), (YAVET,YAVEB), (SLP,YIX)                      ST4   64
      DATA UNITW/62.4/                                                   ST4   66
      L=1                                                                ST4   68
      NSLICE=0                                                           ST4   70
      XL=XBL(ILOW-1)                                                     ST4   72
      YL=YBL(ILOW-1)                                                     ST4   74
      Y1(1)=YL                                                           ST4   76
      Y1(2)=YL                                                           ST4   78
C     ----------------------------------                                 ST4   80
C     DETERMINE SLICES, MOVING IN +X DIRECTION                           ST4   82
C     ----------------------------------                                 ST4   84
      DO 150 I=ILOW,NUMXY                                                ST4   86
         ARCTN=SQ(I-1,1)                                                 ST4   88
         THETA=ATAN(ARCTN)                                               ST4   90
         SN=SIN(THETA)                                                   ST4   92
         CS=COS(THETA)                                                   ST4   94
         GO TO 10                                                        ST4   96
C                                                                        ST4   98
    5    L=L+1                                                           ST4  100
   10    IF (XBL(I)-XCHECK(L)) 30,5,20                                   ST4  102
   15    L=L+1                                                           ST4  104
   20    IF (XCHECK(L)-XCHECK(L+1)) 25,15,25                             ST4  106
   25    XR=XCHECK(L)                                                    ST4  108
         YR=YCHECK(L)                                                    ST4  110
         L=L+1                                                           ST4  112
         IGO=2                                                           ST4  114
         GO TO 35                                                        ST4  116
C                                                                        ST4  118
   30    XR=XBL(I)                                                       ST4  120
         YR=YBL(I)                                                       ST4  122
         IGO=1                                                           ST4  124
C     ----------------------------------                                 ST4  126
C     STORE INFORMATION ON CURRENT SLICE                                 ST4  128
C     ----------------------------------                                 ST4  130
   35    NSLICE=NSLICE+1                                                 ST4  132
         THICK=XR-XL                                                     ST4  134
         CALL WEIGHT (XR,YR,ARCTN,YTL,K,WSLC)                            ST4  136
         WSLC=WSLC*THICK                                                 ST4  138
         XAVE=(XR+XL)/2.                                                 ST4  140
         TP=WSLC                                                         ST4  142
         ALP=(Y1(1)-YTL)/THICK                                           ST4  144
         TOP1(NSLICE)=C(K)*THICK/(CS*CS)                                 ST4  146
         TOP2(NSLICE)=WSLC*ARCTN                                         ST4  148
         TOP3(NSLICE)=ARCTN*PHI(K)                                       ST4  150
```

```
         C     ----------------------------------------
         C     CHECK FOR CONCENTRATED LOADING
         C     ----------------------------------------
  42.              IF (NCONC) 60,60,40
  43.      40      DO 55 J=1,NCONC
  44.                 IF (XQ(J)-XL) 55,55,45
  45.      45         IF (XQ(J)-XR) 50,55,55
  46.      50         TP=TP+QC(J)*(SIN(ANGQC(J))-ARCTN*COS(ANGQC(J)))
  47.                 TOP2(NSLICE)=TOP2(NSLICE)+QC(J)*(ARCTN*SIN(ANGQC(J))+COS(ANG
              1       QC(J)))
  48.                 GO TO 60
         C
  49.      55      CONTINUE
         C     ----------------------------------------
         C     CHECK FOR UNIFORM LOADING
         C     ----------------------------------------
  50.      60      IF (NUNIF) 85,85,65
  51.      65      DO 80 J=1,NUNIF
  52.                 IF (XAVE-XUL(J)) 80,80,70
  53.      70         IF (XAVE-XUR(J)) 75,80,80
  54.      75         SLP=QU(J)*THICK/COS(ATAN(ALP))
  55.                 TOP2(NSLICE)=TOP2(NSLICE)+SLP*(ARCTN*SIN(ANGQU(J))+COS(ANGQU
              1       (J)))
  56.                 TP=TP+SLP*(SIN(ANGQU(J))-ARCTN*COS(ANGQU(J)))
  57.                 GO TO 85
         C
  58.      80      CONTINUE
         C     ----------------------------------------
         C     CHECK FOR G.W.T. CONDITION
         C     ----------------------------------------
  59.      85      IF (IWAT) 145,145,90
  60.      90      DO 100 J=2,NSUR
  61.                 IF (XAVE-XPIEZ(J-1)) 100,95,95
  62.      95         IF (XAVE-XPIEZ(J)) 105,100,100
  63.     100      CONTINUE
  64.              GO TO 145
         C
  65.     105      SLP=(YPIEZ(J)-YPIEZ(J-1))/(XPIEZ(J)-XPIEZ(J-1))
  66.              YIX=YPIEZ(J-1)+SLP*(XAVE-XPIEZ(J-1))
  67.              YAVET=(YTL+YT(1))/2.
  68.              GW=UNITW*THICK
  69.              HT=YIX-YAVET
  70.              IF (HT) 125,125,110
  71.     110      GO TO (120,115), IWAT
  72.     115      HT=HEAD(XAVE,YAVET)-YAVET+DATUM
  73.     120      TP=TP+HT*GW*(1.+ARCTN*ALP)
  74.              TOP2(NSLICE)=TOP2(NSLICE)+HT*GW*(ARCTN-ALP)
  75.     125      YAVEB=(YR+YL)/2.
  76.              HB=YIX-YAVEB
  77.              IF (HB) 145,145,130
  78.     130      GO TO (140,135), IWAT
  79.     135      HB=HEAD(XAVE,YAVEB)-YAVEB+DATUM
  80.     140      TP=TP-GW*HB/(CS*CS)
  81.     145      TOP1(NSLICE)=TOP1(NSLICE)+PHI(K)*TP
  82.              YL=YR
  83.              XL=XR
         C     ----------------------------------------
         C     RETURN TO START OF SUBROUTINE TO PROCESS ANOTHER SLICE IF NECESSARY
         C     ----------------------------------------
  84.              GO TO (150,10), IGO
  85.     150   CONTINUE
  86.           RETURN
  87.           END
```

STATEMENT NUMBER	DEFINITION	REFERENCES		
5	20.	21.		
10	21.	19.	84.	
15	22.	23.		
20	23.	21.		
25	24.	23.		
30	29.	21.		
35	32.	28.		
40	43.	42.		
45	45.	44.		
50	46.	45.		
55	49.	43.	44.	45.
60	50.	42.	48.	
65	51.	50.		
70	53.	52.		
75	54.	53.		
80	58.	51.	52.	53.
85	59.	50.	57.	
90	60.	59.		
95	62.	61.		
100	63.	60.	61.	62.
105	65.	62.		
110	71.	70.		
115	72.	71.		
120	73.	71.		
125	75.	70.		
130	78.	77.		
135	79.	78.		
140	80.	78.		
145	81.	59.	64.	77.
150	85.	14.	84.	

LABEL	TYPE	DEFINITION		REFERENCES
ALP	R	38.		54. 73. 74.
ANGQC	R	3. CD		46. 47.
ANGQU	R	3. CD		55. 56.
ARCTN	R	15.		16. 34. 40. 41. 46. 47. 55.
				56. 73. 74.
ATAN	R	16.	FUNCTION	54.
C	R	3. CD		39.
COS	R	18.	FUNCTION	46. 47. 54. 55. 56.
CS	R	18.		39. 80.
DATUM	R	2. C		72. 79.
DUM1	R	2. CD		
DUM2	R	2. CD		
DUM3	R	5. CD		
GW	R	68.		73. 74. 80.
HB	R	6. E		76. 77. 79. 80.
HEAD	R	72.	FUNCTION	79.
HT	R	6. E		69. 70. 72. 73. 74.
I	I	14.		15. 21. 29. 30.
IDUM	I	2. CD		
IGO	I	27.		31. 84.
ILOW	I	1.		10. 11. 14.
IWAT	I	2. C		59. 71. 78.
J	I	43.		44. 45. 46. 47. 51. 52. 53.
				54. 55. 56. 60. 61. 62. 65.
				66.
K	I	34.		39. 41. 81.
L	I	8.		20. 21. 22. 23. 24. 25. 26.
NCONC	I	2. C		42. 43.
NSLICE	I	1.		9. 32. 32. 39. 40. 41. 47.
				55. 74. 81.
NSUR	I	2. C		60.
NUMXY	I	1.		14.
NUNIF	I	2. C		50. 51.
PHI	R	4. CD		41. 81.
QC	R	3. CD		46. 47.
QU	R	3. CD		54.
SIN	R	17.	FUNCTION	46. 47. 55. 56.
SLP	R	6. E		54. 55. 56. 65. 66.
SN	R	17.		
SQ	R	5. CD		15.
THETA	R	16.		17. 18.
THICK	R	33.		35. 38. 39. 54. 68.
TOP1	R	5. CD		39. 81.
TOP2	R	5. CD		40. 47. 55. 74.
TOP3	R	5. CD		41.
TP	R	37.		46. 56. 73. 80. 81.
UNITW	R	7.	DATA	68.
WEIGHT	R	34.	SUBROUTINE	
WSLC	R	34.		35. 37. 40.
XAVE	R	36.		52. 53. 61. 62. 66. 72. 79.
XBL	R	5. CD		10. 21. 29.
XCHECK	R	4. CD		21. 23. 24.
XL	R	10.		33. 36. 44. 83.
XPIEZ	R	4. CD		61. 62. 65. 66.
XQ	R	3. CD		44. 45.
XQL	R	3. CD		52.
XQR	R	3. CD		53.
XR	R	24.		29. 33. 34. 36. 45. 83.
YAVEB	R	6. E		75. 76. 79.
YAVET	R	6. E		67. 69. 72.
YBL	R	5. CD		11. 30.
YCHECK	R	4. CD		25.
YIX	R	6. E		66. 69. 76.
YL	R	11.		12. 13. 75. 82.
YPIEZ	R	4. CD		65. 66.
YR	R	25.		30. 34. 75. 82.
YTL	R	34.		38. 67.
Y1	R	4. CD		12. 13. 38. 67.

FORSTAT Listing of Subroutine INOUT

```
1.        SUBROUTINE INOUT (IP)
C     -----------------------------------------------------------------
C                               SUBROUTINE INOUT
C     -----------------------------------------------------------------
C     PURPOSE-
C          TO READ-IN, PRINT-OUT, AND STORE IN BLANK COMMON THE PROBLEM
C     PARAMETERS.
C     -----------------------------------------------------------------
C     USAGE-
C          CALL INOUT(IP)
C
C          WHERE  IP = INTEGER CODE INDICATING TYPE OF ANALYSIS
C
C          ALL INPUT VARIABLES ARE PLACED IN BLANK COMMON
C     -----------------------------------------------------------------
C     CONTROL CARDS-
C
C     (A) DESCRIPTION OF PROFILE
C          (1) PROBLEM TITLE CARD
C               TITL       (COL 1-60) ALPHANUMERIC DESCRIPTION OF PROBLEM.
C
C          (2)  PROFILE PARAMETER CARD
C               NBND       (COL 1-2) TOTAL NUMBER OF PROFILE BOUNDARIES.
C               NTOP       (COL 3-4) NUMBER OF GROUND SURFACE BOUNDARIES.
C               NSOIL      (COL 5-6) NUMBER OF SOIL TYPES IN PROFILE.
C               NCONC      (COL 7) NUMBER OF CONCENTRATED LOADINGS ON
C                                  GROUND SURFACE.
C               NUNIF      (COL 8) NUMBER OF UNIFORM LOADINGS ON GROUND
C                                  SURFACE.
C               IWAT       (COL 9) IF IWAT=0, NO G.W.L.
C                                  IF IWAT=1, PRESSURES ARE ASSUMED EQUAL
C                                             TO VERTICAL DISTANCE TO G.W.T.
C                                  IF IWAT=2, PRESSURES ARE CALCULATED US-
C                                             ING 5TH ORDER POLYNOMIAL CO-
C                                             EFFICIENTS GENERATED BY
C                                             PROGRAM FLWNET.
C               NSUR       (COL 10) NUMBER OF COORDINATE POINTS NEEDED TO
C                                     DEFINE G.W.T.  (REQUIRED IF IWAT=1OR2)
C               DATUM      (COL 11-20) ELEVATION DATUM FOR BERNOULLI#S
C                                      EQUATION. (REQUIRED IF IWAT=2)
C               XTOE       (COL 21-30) X-COORD OF TOE. (IF DEFINED)
C               YTOE       (COL 31-40) Y-COORD OF TOE. (IF DEFINED)
C               XTOP       (COL 41-50) X-COORD OF CREST. (IF DEFINED)
C               YTOP       (COL 51-60) Y-COORD OF CREST. (IF DEFINED)
C
C          (3) BOUNDARY CARDS
C            THIS SET INCLUDES ONE CARD/BOUNDARY.  THE ORDER MUST BE
C          GROUND SURFACE BOUNDARIES FIRST, FROM LEFT TO RIGHT.  THE
C          SUBSURFACE BOUNDARIES MUST THEN BE ENTERED IN SUCH A WAY THAT
C          ANY VERTICAL LINE WOULD INTERSECT WITH DEPTH BOUNDARIES THAT
C          ARE IN ANY SUBSEQUENT ORDER.  (THIS IS NECESSARY FOR SLICE
C          WEIGHT CALCULATIONS)
C               BNDS(I,1)  (COL 1-10)  X-COORD OF LEFT POINT OF BOUNDARY.
C               BNDS(I,2)  (COL 11-20) Y-COORD OF LEFT POINT OF BOUNDARY.
C               BNDS(I,3)  (COL 21-30) X-COORD OF RIGHT POINT OF BOUNDARY.
C               BNDS(I,4)  (COL 31-40) Y-COORD OF RIGHT POINT OF BOUNDARY.
C               ITP(I)     (COL 41-42) INTEGER CODE REPRESENTING THE
C                                      ORDER IN WHICH THE SOIL TYPE BELOW
C                                      THE BOUNDARY IS READ LATER.
C
C          (4) SOIL PROPERTY CARD(S)
C            THIS SET INCLUDES ONE CARD/SOIL TYPE. THE ORDER MUST
C          CORRESPOND TO THE INTEGER CODING DESCRIBED IN (3).
C               GAMMA(I)   (COL 1-10)  TOTAL UNIT WEIGHT.
C               C(I)       (COL 11-20) MOHR-COULOMB COHESION.
C               PHI(I)     (COL 21-30) MOHR-COULOMB ANGLE OF INTERNAL
C                                      FRICTION.
C
C     ---------------------------------
C     DEPENDING UPON THE INFORMATION ON CARD (2), SOME OR ALL OF THE
C     FOLLOWING SETS MAY BE OMITTED.
C
C          (5) UNIFORM LOADING CARD(S)
C            THIS SET INCLUDES ONE CARD/LOADING.
C               QU(I)      (COL 1-10)  MAGNITUDE OF LOAD.
C               ANGQU(I)   (COL 11-20) ANGLE OF LOAD DIRECTION MEASURED
C                                      COUNTER-CLOCKWISE FROM HORIZONTAL.
C               XQL(I)     (COL 21-30) X-COORD OF LEFT SIDE OF LOAD.
C               XQR(I)     (COL 31-40) X-COORD OF RIGHT SIDE OF LOAD.
C
```

```
      C        (6) CONCENTRATED LOADING CARD(S)
      C          THIS SET INCLUDES ONE CARD/LOADING.
      C              QC(I)       (COL 1-10)  MAGNITUDE OF LOAD.
      C              ANGQC(I)    (COL 11-20) ANGLE OF LOAD DIRECTION MEASURED
      C                                      COUNTER-CLOCKWISE FROM HORIZONTAL.
      C              XQ(I)       (COL 21-30) X-COORD OF LOAD.
      C
      C        (7) G.W.L. CARDS
      C          THIS SET INCLUDES ONE CARD/COORDINATE POINT. THE ORDER MUST
      C        BE FROM LEFT TO RIGHT.
      C              XPIEZ(I)    (COL 1-10)  X-COORD OF G.W.L. POINT.
      C              YPIEZ(I)    (COL 11-20) Y-COORD OF G.W.L. POINT.
      C
      C        (8) 5TH ORDER FLOWNET COEFFICIENT CARDS
      C          THIS SET INCLUDES ONE CARD/COEFFICIENT.  THE ORDER MUST BE
      C        THE SAME AS THE OUTPUT OF PROGRAM  FLWNET.  THE FORMAT MUST BE
      C        E10.3.
      C              COEFF(I)    (COL 1-10) POLYNOMIAL COEFFICIENT.
      C
      C
      C     COMPLETE CONTROL CARDS WITH PARTS (B) AND (C) DESCRIBED IN MAIN
      C     PROGRAM.
      C     ----------------------------------------------------------------
      C     SYSTEM ROUTINES-
      C          FUNCTION TAN
      C     ----------------------------------------------------------------
 2.           DIMENSION TITL(10)
 3.           COMMON COEFF(21),XTOE,YTOE,XTOP,YTOP,DATUM,NBND,NTOP,ITP(15)
 4.           COMMON NSUR,IWAT,NCONC,NUNIF,BNDS(20,4),EQ(20,2),GAMMA(15)
 5.           COMMON XQL(5),XQR(5),XQ(5),QU(5),ANGQU(5),QC(5),ANGQC(5)
 6.           COMMON C(15),PHI(15),XPIEZ(9),YPIEZ(9)
 7.           DATA PI180/0.01745329/
      C     ---------------------------------
      C     READ DATA
      C     ---------------------------------
 8.           READ (5,150) (TITL(I),I=1,10)
 9.           READ (5,160) NBND,NTOP,NSOIL,NCONC,NUNIF,IWAT,NSUR,DATUM,XTOE,YTOE
             1,XTOP,YTOP
10.           READ (5,165) ((BNDS(I,J),J=1,4),ITP(I),I=1,NBND)
11.           READ (5,170) (GAMMA(I),C(I),PHI(I),I=1,NSOIL)
12.           IF (NUNIF) 10,10,5
13.       5   READ (5,155) (QU(I),ANGQU(I),XQL(I),XQR(I),I=1,NUNIF)
14.      10   IF (NCONC) 20,20,15
15.      15   READ (5,170) (QC(I),ANGQC(I),XQ(I),I=1,NCONC)
16.      20   IF (IWAT) 35,35,25
17.      25   READ (5,175) (XPIEZ(I),YPIEZ(I),I=1,NSUR)
18.           GO TO (35,30), IWAT
19.      30   READ (5,180) (COEFF(I),I=1,21)
      C     ---------------------------------
      C     PRINT AND REDUCE DATA
      C     ---------------------------------
20.      35   WRITE (6,185)
21.           GO TO (40,45,50), IP
22.      40   WRITE (6,190)
23.           GO TO 55
      C
24.      45   WRITE (6,195)
25.           GO TO 55
      C
26.      50   WRITE (6,200)
27.      55   WRITE (6,205) (TITL(I),I=1,10),XTOE,XTOP,YTOE,YTOP
28.           WRITE (6,210) NTOP,NBND
29.           DO 75 I=1,NBND
30.              H=BNDS(I,4)-BNDS(I,2)
31.              IF (H) 65,60,65
32.      60      EQ(I,1)=0.0
33.              GO TO 70
      C
34.      65      EQ(I,1)=H/(BNDS(I,3)-BNDS(I,1))
35.      70      EQ(I,2)=BNDS(I,2)-EQ(I,1)*BNDS(I,1)
36.      75   WRITE (6,215) I,(BNDS(I,J),J=1,4),ITP(I)
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```
      WRITE (6,220) NSOIL
      DO 80 I=1,NSOIL
         WRITE (6,225) I,GAMMA(I),C(I),PHI(I)
80    PHI(I)=TAN(PHI(I)*PI180)
      WRITE (6,230) NUNIF
      IF (NUNIF) 95,95,85
85    WRITE (6,235)
      DO 90 I=1,NUNIF
         WRITE (6,240) QU(I),ANGQU(I),XQL(I),XQR(I)
90    ANGQU(I)=ANGQU(I)*PI180
95    WRITE (6,245) NCONC
      IF (NCONC) 110,110,100
100   WRITE (6,250)
      DO 105 I=1,NCONC
         WRITE (6,255) QC(I),ANGQC(I),XQ(I)
105   ANGQC(I)=ANGQC(I)*PI180
110   IF (IWAT) 115,115,120
115   WRITE (6,260)
      GO TO 145
C
120   WRITE (6,265) NSUR
      DO 125 I=1,NSUR
125   WRITE (6,270) I,XPIEZ(I),YPIEZ(I)
      GO TO (130,135), IWAT
130   WRITE (6,275)
      GO TO 145
C
135   WRITE (6,285)
      DO 140 I=1,21
140   WRITE (6,280) I,COEFF(I)
145   RETURN
C
150   FORMAT (10A6)
155   FORMAT (4F10.3)
160   FORMAT (3I2,4I1,5F10.0)
165   FORMAT (4F10.4,I2)
170   FORMAT (3F10.4)
175   FORMAT (2F10.4)
180   FORMAT (E10.3)
185   FORMAT (1H123X,≠--SLOPE STABILITY ANALYSIS--≠)
190   FORMAT (1H 25X,≠TAYLOR  METHOD OF SLICES≠///)
195   FORMAT (1H 21X,≠MODIFIED BISHOP METHOD OF SLICES≠/23X,≠MOMENT CENT
     1ER = CIRCLE CENTER≠///)
200   FORMAT (1H 21X,≠MODIFIED BISHOP METHOD OF SLICES≠/27X,≠MOMENT CENT
     1ER = +Y INF≠///)
205   FORMAT (1H 10X,≠PROBLEM DESCRIPTION   ≠,10A6////4X,≠PROFILE PARAME
     1TERS≠//8X,≠TOE COORDINATES≠,20X,≠CREST COORDINATES≠//12X,≠XTOE =≠,
     2F10.1,20X,≠XTOP =≠,F10.1/12X,≠YTOE =≠,F10.1,20X,≠YTOP =≠,F10.1/)
210   FORMAT (1H //8X,≠BOUNDARY COORDINATES≠//12X,I2,≠ TOP   BOUNDARIES≠
     1/12X,I2,≠ TOTAL BOUNDARIES≠//12X,≠BNO NO.≠,4X,≠X-LEFT≠,4X,≠Y-LEFT≠
     2,4X,≠X-RIGHT≠,3X,≠Y-RIGHT≠,4X,≠SOIL TYPE BELOW≠)
215   FORMAT (1H 12X,I3,2X,4F10.1,12X,I2)
220   FORMAT (1H ///8X,≠SOIL PROPERTIES≠//11X,I2,≠ TYPES OF SOIL≠//16X,≠
     1TYPE NO.≠,3X,≠GAMMA≠,6X,≠C≠,9X,≠PHI≠)
225   FORMAT (1H 16X,I2,3X,3F10.1)
230   FORMAT (1H ///8X,≠TOP BOUNDARY LOADING≠//11X,I2,≠ UNIFORM LOADING≠
     1)
235   FORMAT (1H013X,≠QU≠,8X,≠ANGQU≠,5X,≠XQ-LEFT≠,3X,≠XQ-RIGHT≠)
240   FORMAT (1H 8X,4F10.2)
245   FORMAT (1H010X,I2,≠ CONCENTRATED LOADING≠)
250   FORMAT (1H014X,≠QC≠,8X,≠ANGQC≠,5X,≠XC≠)
255   FORMAT (1H 8X,3F10.2)
260   FORMAT (1H ///8X,≠NO G.W.T. HAS BEEN SPECIFIED≠)
265   FORMAT (1H ///8X,≠G.W.T. SPECIFIED BY≠,I3,≠ COORDINATE POINTS≠//13
     1X,≠NO.≠,6X,≠X-GWT≠,7X,≠Y-GWT≠)
270   FORMAT (1H 12X,I2,2F12.2)
275   FORMAT (1H //8X≠VERTICAL DISTANCE TO G.W.T. SET EQUAL TO PRESSURE≠
     1)
280   FORMAT (1H 11X,I2,5X,E10.3)
285   FORMAT (1H //8X,≠FIFTH ORDER POLYNOMIAL APPROXIMATES FLOW NET≠//12
     1X,≠I≠,8X,≠A(I)≠/)
      END
```

STATEMENT NUMBER	DEFINITION		REFERENCES	
5	13.		12.	
10	14.		12.	
15	15.		14.	
20	16.		14.	
25	17.		16.	
30	19.		18.	
35	20.		16.	18.
40	22.		21.	
45	24.		21.	
50	26.		21.	
55	27.		23.	25.
60	32.		31.	
65	34.		31.	
70	35.		33.	
75	36.		29.	
80	40.		38.	
85	43.		42.	
90	46.		44.	
95	47.		42.	
100	49.		48.	
105	52.		50.	
110	53.		48.	
115	54.		53.	
120	56.		53.	
125	58.		57.	
130	60.		59.	
135	62.		59.	
140	64.		63.	
145	65.		55.	61.
150	66.	FORMAT	8.	
155	67.	FORMAT	13.	
160	68.	FORMAT	9.	
165	69.	FORMAT	10.	
170	70.	FORMAT	11.	15.
175	71.	FORMAT	17.	
180	72.	FORMAT	19.	
185	73.	FORMAT	20.	
190	74.	FORMAT	22.	
195	75.	FORMAT	24.	
200	76.	FORMAT	26.	
205	77.	FORMAT	27.	
210	78.	FORMAT	28.	
215	79.	FORMAT	36.	
220	80.	FORMAT	37.	
225	81.	FORMAT	39.	
230	82.	FORMAT	41.	
235	83.	FORMAT	43.	
240	84.	FORMAT	45.	
245	85.	FORMAT	47.	
250	86.	FORMAT	49.	
255	87.	FORMAT	51.	
260	88.	FORMAT	54.	
265	89.	FORMAT	56.	
270	90.	FORMAT	58.	
275	91.	FORMAT	60.	
280	92.	FORMAT	64.	
285	93.	FORMAT	62.	

```
 LABEL      TYPE     DEFINITION                                      REFERENCES

ANGQC        R          5. CD                   15.    51.    52.
ANGQU        R          5. CD                   13.    45.    46.
BNDS         R          4. CD                   10.    30.    34.    35.    36.
C            R          6. CD                   11.    39.
COEFF        R          3. CD                   19.    64.
DATUM        R          3. C                     9.
EQ           R          4. CD                   32.    34.    35.
GAMMA        R          4. CD                   11.    39.
H            R         30.                      31.    34.
I            I          8.                      10.    11.    13.    15.    17.    19.    27.
                                                29.    30.    32.    34.    35.    36.    38.
                                                39.    40.    44.    45.    46.    50.    51.
                                                52.    57.    58.    63.    64.
IP           I          1.                      21.
ITP          I          3. CD                   10.    36.
IWAT         I          4. C                     9.    16.    18.    53.    59.
J            I         10.                      36.
NBND         I          3. C                     9.    10.    28.    29.
NCONC        I          4. C                     9.    14.    15.    47.    48.    50.
NSOIL        I          9.                      11.    37.    38.
NSUR         I          4. C                     9.    17.    56.    57.
NTOP         I          3. C                     9.    28.
NUNIF        I          4. C                     9.    12.    13.    41.    42.    44.
PHI          R          6. CD                   11.    39.    40.
PI180        R          7.        DATA          40.    46.    52.
QC           R          5. CD                   15.    51.
QU           R          5. CD                   13.    45.
TAN          R         40.        FUNCTION
TITL         R          2.  D                    8.    27.
XPIEZ        R          6. CD                   17.    58.
XQ           R          5. CD                   15.    51.
XQL          R          5. CD                   13.    45.
XQR          R          5. CD                   13.    45.
XTOE         R          3. C                     9.    27.
XTOP         R          3. C                     9.    27.
YPIEZ        R          6. CD                   17.    58.
YTOE         R          3. C                     9.    27.
YTOP         R          3. C                     9.    27.
```

FORSTAT Listing of Subroutine CROSS

```
      SUBROUTINE CROSS (ISTOP,XCEN,YCEN,R)
C     ------------------------------------------------------------------
C                               SUBROUTINE CROSS
C     ------------------------------------------------------------------
C     PURPOSE-
C          TO FIND ENTRANCE-EXIT POINTS, INTERMEDIATE SLICE POINTS, AND
C     OTHER POINTS OF IMPORTANCE FOR A GIVEN SLIP CIRCLE AND THE PROFILE
C     BOUNDARIES.
C     ------------------------------------------------------------------
C     USAGE-
C          CALL CROSS(ISTOP,XCEN,YCEN,R)
C
C          WHERE ISTOP = INTEGER CODE INDICATING SUCCESSFULL CALL
C                XCEN  = X-COORD. OF CIRCLE CENTER
C                YCEN  = Y-COORD. OF CIRCLE CENTER
C                R     = RADIUS OF CIRCLE
C
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON
C     ------------------------------------------------------------------
C     SYSTEM ROUTINES-
C          FUNCTION ABS
C          FUNCTION SQRT
C     ------------------------------------------------------------------
C     NOTE-
C          IN ORDER TO ACCOUNT FOR MACHINE ROUNDING, A DIFFERENCE BETWEEN
C     TWO VARIABLES OF LESS THAN 10.E-4 IS TAKEN AS EQUAL TO ZERO.  THIS
C     VALUE IS DEFINED IN THE DATA STATEMENT.
C     ------------------------------------------------------------------
      COMMON DUM1(26),NBND,NTOP,IDUM(17),NCONC,NUNIF,BNDS(20,4)
      COMMON EQ(20,2),DUM2(15),XQL(5),XQR(5),XQ(5),DUM3(78),XCHECK(25)
      COMMON YCHECK(25),EXIT(2,2)
      DATA ZERO/10.E-4/
      EQUIVALENCE (C,CHAR), (JJ,I), (N,K), (M,LL)
      YDIST(XDIST)=YCEN-SQRT(RSQ-(XDIST-XCEN)**2)
      L=0
      N=1
      RSQ=R*R
      CSUM=XCEN*XCEN+YCEN*YCEN-RSQ
C     --------------------------------
C     FIND ALL CIRCLE-BOUNDARY INTERSECTIONS
C     --------------------------------
      DO 115 JJ=1,NBND
         GO TO (5,5,15), N
5        IF (NTOP-JJ) 230,10,10
10       J=NTOP+1-JJ
         GO TO 20
C
15       J=JJ
20       A=1.+EQ(J,1)*EQ(J,1)
         B=XCEN+EQ(J,1)*(YCEN-EQ(J,2))
         C=CSUM+EQ(J,2)*(EQ(J,2)-2.*YCEN)
         CHAR=B*B-A*C
         IF (ABS(CHAR)-ZERO) 30,25,25
25       IF (CHAR) 115,30,35
30       KK=1
         GO TO 40
C
35       KK=2
         CHAR=SQRT(CHAR)
40       DO 110 M=1,KK
            GO TO (45,50), M
45          X=(B+CHAR)/A
            GO TO 55
C
50          X=(B-CHAR)/A
55          TEMP=X-BNDS(J,1)
            IF (ABS(TEMP)-ZERO) 90,60,60
60          IF (TEMP) 110,90,65
65          TEMP=X-BNDS(J,3)
            IF (ABS(TEMP)-ZERO) 110,70,70
70          IF (TEMP) 75,110,110
75          Y=X*EQ(J,1)+EQ(J,2)
            IF (Y-BNDS(J,2)) 80,95,85
80          IF (Y-BNDS(J,4)) 110,110,95
85          IF (Y-BNDS(J,4)) 95,110,110
90          X=BNDS(J,1)
            Y=X*EQ(J,1)+EQ(J,2)
95          GO TO (100,100,105), N
```

```
100          NNN=3-N                                                    CR 158
             EXIT(NNN,1)=X                                              CR 160
             EXIT(NNN,2)=Y                                              CR 162
             N=N+1                                                      CR 164
             GO TO 110                                                  CR 166
C                                                                       CR 168
105          L=L+1                                                      CR 170
             XCHECK(L)=X                                                CR 172
             YCHECK(L)=Y                                                CR 174
110        CONTINUE                                                     CR 176
115     CONTINUE                                                        CR 178
        IF (EXIT(2,2)-YCEN) 120,120,235                                 CR 180
C    ----------------------------------                                 CR 182
C    FIND ALL BOUNDARY END-POINTS WITHIN CIRCLE LIMITS                  CR 184
C    ----------------------------------                                 CR 186
120     DO 140 J=1,NBND                                                 CR 188
        DO 140 K=1,3,2                                                  CR 190
           IF (BNDS(J,K)-EXIT(1,1)) 140,140,125                         CR 192
125        IF (BNDS(J,K)-EXIT(2,1)) 130,140,140                         CR 194
130        Y=YDIST(BNDS(J,K))                                           CR 196
           IF (Y-BNDS(J,K+1)) 135,140,140                               CR 198
135        L=L+1                                                        CR 200
           XCHECK(L)=BNDS(J,K)                                          CR 202
           YCHECK(L)=Y                                                  CR 204
140     CONTINUE                                                        CR 206
C    ----------------------------------                                 CR 208
C    CHECK FOR UNIFORM LOADINGS                                         CR 210
C    ----------------------------------                                 CR 212
        IF (NUNIF) 180,180,145                                          CR 214
145     DO 175 J=1,NUNIF                                                CR 216
        DO 175 I=1,2                                                    CR 218
           GO TO (150,155), I                                           CR 220
150        X=XQL(J)                                                     CR 222
           GO TO 160                                                    CR 224
C                                                                       CR 226
155        X=XQR(J)                                                     CR 228
160        IF (X-EXIT(1,1)) 175,175,165                                 CR 230
165        IF (X-EXIT(2,1)) 170,175,175                                 CR 232
170        L=L+1                                                        CR 234
           XCHECK(L)=X                                                  CR 236
           YCHECK(L)=YDIST(XCHECK(L))                                   CR 238
175     CONTINUE                                                        CR 240
C    ----------------------------------                                 CR 242
C    CHECK FOR CONCENTRATED LOADINGS                                    CR 244
C    ----------------------------------                                 CR 246
180     IF (NCONC) 205,205,185                                          CR 248
185     DO 200 J=1,NCONC                                                CR 250
           IF (XQ(J)-EXIT(1,1)) 200,200,190                             CR 252
190        IF (XQ(J)-EXIT(2,1)) 195,200,200                             CR 254
195        L=L+2                                                        CR 256
           XCHECK(L-1)=0.999*XQ(J)                                      CR 258
           XCHECK(L)=1.001*XQ(J)                                        CR 260
           YCHECK(L-1)=YDIST(XCHECK(L-1))                               CR 262
           YCHECK(L)=YDIST(XCHECK(L))                                   CR 264
200     CONTINUE                                                        CR 266
205     LL=L-1                                                          CR 268
        IF (LL) 225,225,210                                             CR 270
C    ----------------------------------                                 CR 272
C    ORDER  XCHECK  ARRAY                                               CR 274
C    ----------------------------------                                 CR 276
210     DO 220 J=1,LL                                                   CR 278
           K=J+1                                                        CR 280
        DO 220 JJ=K,L                                                   CR 282
           IF (XCHECK(J)-XCHECK(JJ)) 220,220,215                        CR 284
215        TEMP=XCHECK(J)                                               CR 286
           XCHECK(J)=XCHECK(JJ)                                         CR 288
           XCHECK(JJ)=TEMP                                              CR 290
           TEMP=YCHECK(J)                                               CR 292
           YCHECK(J)=YCHECK(JJ)                                         CR 294
           YCHECK(JJ)=TEMP                                              CR 296
220     CONTINUE                                                        CR 298
225     XCHECK(L+1)=999999.                                             CR 300
        RETURN                                                          CR 302
230     N=N-1                                                           CR 304
        WRITE (6,245) R,N                                               CR 306
        GO TO 240                                                       CR 308
C                                                                       CR 310
235     WRITE (6,250) R                                                 CR 312
240     ISTOP=2                                                         CR 314
        RETURN                                                          CR 316
C                                                                       CR 318
245     FORMAT (32X,F8.2,10X,I2,# TOP BOUNDARY-CIRCLE INTERSECTION#)    CR 320
250     FORMAT (32X,F8.2,10X,#Y-EXIT GREATER THAN Y-CENTER#)            CR 322
        END                                                             CR 324-
```

STATEMENT NUMBER	DEFINITION		REFERENCES						
5	14.		1.						
10	15.		14.						
15	17.		13.						
20	18.		16.						
25	23.		22.						
30	24.		22.	23.					
35	26.		23.						
40	28.		25.						
45	30.		29.						
50	32.		29.						
55	33.		31.						
60	35.		34						
65	36.		35.						
70	38.		37.						
75	39.		38.						
80	41.		40.						
85	42.		40.						
90	43.		34.	35.					
95	45.		40.	41.	42.				
100	46.		45.						
105	51.		45.						
110	54.		28.	35.	37.	38.	41.	42.	50.
115	55.		12.	23.					
120	57.		56.						
125	60.		59.						
130	61.		60.						
135	63.		62.						
140	66.		57.	58.	59.	60.	62.		
145	68.		67.						
150	71.		70.						
155	73.		70.						
160	74.		72.						
165	75.		74.						
170	76.		75.						
175	79.		68.	69.	74.	75.			
180	80.		67.						
185	81.		80.						
190	83.		82.						
195	84.		83.						
200	89.		81.	82.	83.				
205	90.		80.						
210	92.		91.						
215	96.		95.						
220	102.		92.	94.	95.				
225	103.		91.						
230	105.		14.						
235	108.		56.						
240	109.		107.						
245	111.	FORMAT	106.						
250	112.	FORMAT	108.						

LABEL	TYPE	DEFINITION		REFERENCES						
A	R	18.		21.	30.	32.				
ABS	R	22.	FUNCTION	34.	37.					
B	R	19.		21.	30.	32.				
BNDS	R	2. CD		33.	36.	40.	41.	42.	43.	59.
				60.	61.	62.	64.			
C	R	6. E		20.	21.					
CHAR	R	6. E		21.	22.	23.	27.	30.	32.	
CSUM	R	11.		20.						
DUM1	R	2. CD								
DUM2	R	3. CD								
DUM3	R	3. CD								
EQ	R	3. CD		18.	19.	20.	39.	44.		
EXIT	R	4. CD		47.	48.	56.	59.	60.	74.	75.
				82.	83.					
I	I	6. E		69.	70.					
IDUM	I	2. CD								
ISTOP	I	1.		109.						
J	I	15.		17.	18.	19.	20.	33.	36.	39.
				40.	41.	42.	43.	44.	57.	59.
				60.	61.	62.	64.	68.	71.	73.
				81.	82.	83.	85.	86.	92.	93.
				95.	96.	97.	99.	100.		
JJ	I	6. E		12.	14.	15.	17.	94.	95.	97.
				98.	100.	101.				
K	I	6. E		58.	59.	60.	61.	62.	64.	93.
				94.						
KK	I	24.		26.	28.					
L	I	8.		51.	52.	53.	63.	64.	65.	76.
				77.	78.	84.	85.	86.	87.	88.
				90.	94.	103.				
LL	I	6. E		90.	91.	92.				
M	I	6. E		28.	29.					
N	I	6. E		9.	13.	45.	46.	49.	105.	106.
NBND	I	2. C		12.	57.					
NCONC	I	2. C		80.	81.					
NNN	I	46.		47.	48.					
NTOP	I	2. C		14.	15.					
NUNIF	I	2. C		67.	68.					
R	R	1.		10.	106.	108.				
RSQ	R	7.		10.	11.					
SQRT	R	7.	FUNCTION	27.						
TEMP	R	33.		34.	35.	36.	37.	38.	96.	98.
				99.	101.					
X	R	30.		32.	33.	36.	39.	43.	44.	47.
				52.	71.	73.	74.	75.	77.	
XCEN	R	1.		7.	11.	19.				
XCHECK	R	3. CD		52.	64.	77.	78.	85.	86.	87.
				88.	95.	96.	97.	98.	103.	
XDIST	R	7.								
XQ	R	3. CD		82.	83.	85.	86.			
XQL	R	3. CD		71.						
XQR	R	3. CD		73.						
Y	R	39.		40.	41.	42.	44.	48.	53.	61.
				62.	65.					
YCEN	R	1.		7.	11.	11.	19.	20.	56.	
YCHECK	R	4. CD		53.	65.	78.	87.	88.	99.	100.
				101.						
YDIST	R ASF	7.		61.	78.	87.	88.			
ZERO	R	5.	DATA	22.	34.	37.				

FORSTAT Listing of Subroutine SLPBND

```
      SUBROUTINE SLPBND (ILOW,NUMXY)
C     ------------------------------------------------------------------
C                            SUBROUTINE SLPBND
C     ------------------------------------------------------------------
C     PURPOSE-
C          TO FIND INTERMEDIATE SLICE POINTS FOR A GIVEN IRREGULAR SLIP
C     SURFACE AND THE PROFILE BOUNDARIES.
C     ------------------------------------------------------------------
C     USAGE-
C          CALL SLPBND(ILOW,NUMXY)
C
C          WHERE  ILOW  = SUBSCRIPT OF 2ND COORD POINT OF SLIP SURFACE
C                 NUMXY = SUBSCRIPT OF LAST COORD POINT OF SLIP SURFACE
C
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON
C     ------------------------------------------------------------------
C     SYSTEM ROUTINES-
C          FUNCTION ABS
C     ------------------------------------------------------------------
C     NOTE-
C          IN ORDER TO ACCOUNT FOR MACHINE ROUNDING, A DIFFERENCE BETWEEN
C     TWO VARIABLES OF LESS THAN 10.E-4 IS TAKEN AS EQUAL TO ZERO.  THIS
C     VALUE IS DEFINED IN THE DATA STATEMENT.
C     ------------------------------------------------------------------
      COMMON DUM1(26),NBND,NTOP,IDUM(17),NCONC,NUNIF,BNDS(20,4)
      COMMON EQ(20,2),DUM2(15),XQL(5),XQR(5),XQ(5),DUM3(78),XCHECK(25)
      COMMON YCHECK(25),DUM4(154),X(12),DUM5(12),SEQ(11,2)
      DATA ZERO/10.E-4/
      ICHECK=0
C     ----------------------------------
C     FIND SURFACE-BOUNDARY INTERSECTIONS AND INTERIOR BOUNDARY POINTS
C     ----------------------------------
      DO 55 L=ILOW,NUMXY
      DO 55 K=1,NBND
         IF (K-NTOP) 35,35,5
    5    TEMP=EQ(K,1)-SEQ(L-1,1)
         IF (ABS(TEMP)-ZERO) 35,10,10
   10    XI=(SEQ(L-1,2)-EQ(K,2))/TEMP
         IF (XI-X(L-1)-ZERO) 35,35,15
   15    IF (XI-X(L)+ZERO) 20,35,35
   20    IF (XI-BNDS(K,1)-ZERO) 35,35,25
   25    IF (XI-BNDS(K,3)+ZERO) 30,35,35
   30    ICHECK=ICHECK+1
         XCHECK(ICHECK)=XI
         YCHECK(ICHECK)=XI*SEQ(L-1,1)+SEQ(L-1,2)
   35 DO 55 I=1,3,2
         IF (BNDS(K,I)-X(L-1)-ZERO) 55,55,40
   40    IF (BNDS(K,I)-X(L)+ZERO) 45,55,55
   45    YI=BNDS(K,I)*SEQ(L-1,1)+SEQ(L-1,2)
         IF (BNDS(K,I+1)-YI+ZERO) 55,55,50
   50    ICHECK=ICHECK+1
         XCHECK(ICHECK)=BNDS(K,I)
         YCHECK(ICHECK)=YI
   55 CONTINUE
C     ----------------------------------
C     CHECK FOR UNIFORM LOADING
C     ----------------------------------
      IF (NUNIF) 110,110,60
   60 DO 105 K=1,NUNIF
      DO 105 I=1,2
         GO TO (65,70), I
   65    XI=XQL(K)
         GO TO 75
C
   70    XI=XQR(K)
   75    IF (XI-X(ILOW-1)) 105,105,80
   80    IF (XI-X(NUMXY)) 85,105,105
   85    ICHECK=ICHECK+1
         XCHECK(ICHECK)=XI
         DO 100 L=ILOW,NUMXY
            IF (XI-X(L)) 90,100,100
   90       IF (XI-X(L-1)) 100,100,95
   95       YCHECK(ICHECK)=SEQ(L-1,1)*XI+SEQ(L-1,2)
            GO TO 105
C
  100    CONTINUE
  105 CONTINUE
```

```
        C     -----------------------------------
        C     CHECK FOR CONCENTRATED LOADING
        C     -----------------------------------
 47.    110     IF (NCONC) 150,150,115
 48.    115     DO 145 K=1,NCONC
 49.                IF (XQ(K)-X(ILOW-1)) 145,145,120
 50.    120         IF (XQ(K)-X(NUMXY)) 125,145,145
 51.    125         ICHECK=ICHECK+2
 52.                XCHECK(ICHECK-1)=0.999*XQ(K)
 53.                XCHECK(ICHECK)=1.001*XQ(K)
 54.                DO 140 L=ILOW,NUMXY
 55.                   IF (XQ(K)-X(L)) 130,140,140
 56.    130            IF (XQ(K)-X(L-1)) 140,140,135
 57.    135            YCHECK(ICHECK)=SEQ(L-1,1)*XCHECK(ICHECK)+SEQ(L-1,2)
 58.                   YCHECK(ICHECK-1)=SEQ(L-1,1)*XCHECK(ICHECK-1)+SEQ(L-1,2)
 59.                   GO TO 145
        C
 60.    140         CONTINUE
 61.    145     CONTINUE
 62.    150     K=ICHECK-1
 63.            IF (K) 170,170,155
        C     -----------------------------------
        C     ORDER  XCHECK  ARRAY
        C     -----------------------------------
 64.    155     DO 165 I=1,K
 65.                L=I+1
 66.            DO 165 II=L,ICHECK
 67.                IF (XCHECK(I)-XCHECK(II)) 165,165,160
 68.    160         TEMP=XCHECK(I)
 69.                XCHECK(I)=XCHECK(II)
 70.                XCHECK(II)=TEMP
 71.                TEMP=YCHECK(I)
 72.                YCHECK(I)=YCHECK(II)
 73.                YCHECK(II)=TEMP
 74.    165     CONTINUE
 75.    170     XCHECK(ICHECK+1)=999999.
 76.            RETURN
 77.            END
```

STATEMENT NUMBER	DEFINITION	REFERENCES					
5	10.	9.					
10	12.	11.					
15	14.	13.					
20	15.	14.					
25	16.	15.					
30	17.	16.					
35	20.	9.	11.	13.	14.	15.	16.
40	22.	21.					
45	23.	22.					
50	25.	24.					
55	28.	7.	8.	20.	21.	22.	24.
60	30.	29.					
65	33.	32.					
70	35.	32.					
75	36.	34.					
80	37.	36.					
85	38.	37.					
90	42.	41.					
95	43.	42.					
100	45.	40.	41.	42.			
105	46.	30.	31.	36.	37.	44.	
110	47.	29.					
115	48.	47.					
120	50.	49.					
125	51.	50.					
130	56.	55.					
135	57.	56.					
140	60.	54.	55.	56.			
145	61.	48.	49.	50.	59.		
150	62.	47.					
155	64.	63.					
160	68.	67.					
165	74.	64.	66.	67.			
170	75.	63.					

LABEL	TYPE	DEFINITION		REFERENCES						
ABS	R	11.	FUNCTION							
BNDS	R	2. CD		15.	16.	21.	22.	23.	24.	26.
DUM1	R	2. CD								
DUM2	R	3. CD								
DUM3	R	3. CD								
DUM4	R	4. CD								
DUM5	R	4. CD								
EQ	R	3. CD		10.	12.					
I	I	20.		21.	22.	23.	24.	26.	31.	32.
				64.	65.	67.	68.	69.	71.	72.
ICHECK	I	6.		17.	18.	19.	25.	26.	27.	38.
				39.	43.	51.	52.	53.	57.	58.
				62.	66.	75.				
IDUM	I	2. CD								
II	I	66.		67.	69.	70.	72.	73.		
ILOW	I	1.		7.	36.	40.	49.	54.		
K	I	8.		9.	10.	12.	15.	16.	21.	22.
				23.	24.	26.	30.	33.	35.	48.
				49.	50.	52.	53.	55.	56.	62.
				63.	64.					
L	I	7.		10.	12.	13.	14.	19.	21.	22.
				23.	40.	41.	42.	43.	54.	55.
				56.	57.	58.	65.	66.		
NBND	I	2. C		8.						
NCONC	I	2. C		47.	48.					
NTOP	I	2. C		9.						
NUMXY	I	1.		7.	37.	40.	50.	54.		
NUNIF	I	2. C		29.	30.					
SEQ	R	4. CD		10.	12.	19.	23.	43.	57.	58.
TEMP	R	10.		11.	12.	68.	70.	71.	73.	
X	R	4. CD		13.	14.	21.	22.	36.	37.	41.
				42.	49.	50.	55.	56.		
XCHECK	R	3. CD		18.	26.	39.	52.	53.	57.	58.
				67.	68.	69.	70.	75.		
XI	R	12.		13.	14.	15.	16.	18.	19.	33.
				35.	36.	37.	39.	41.	42.	43.
XQ	R	3. CD		49.	50.	52.	53.	55.	56.	
XQL	R	3. CD		33.						
XQR	R	3. CD		35.						
YCHECK	R	4. CD		19.	27.	43.	57.	58.	71.	72.
				73.						
YI	R	23.		24.	27.					
ZERO	R	5.	DATA	11.	13.	14.	15.	16.	21.	22.
				24.						

FORSTAT Listing of Subroutine WEIGHT

```
      SUBROUTINE WEIGHT (XR,YR,TNP,YTL,K,WSLC)
C     -----------------------------------------------------------------
C                               SUBROUTINE WEIGHT
C     -----------------------------------------------------------------
C     PURPOSE-
C          TO CALCULATE THE WEIGHT OF A GIVEN SLICE AND TO DETERMINE
C     THE SOIL TYPE AT THE BASE OF THE SLICE.
C     -----------------------------------------------------------------
C     USAGE-
C          CALL WEIGHT(XR,YR,TNP,YTL,K,WSLC)
C
C          WHERE XR   = AT CALL, BOTTOM RIGHT X-COORD. OF SLICE
C                YR   = AT CALL, BOTTOM RIGHT Y-COORD. OF SLICE
C                TNP  = AT CALL, SLOPE  OF LOWER BOUNDARY OF SLICE
C                YTL  = AT RETURN, TOP LEFT Y-COORD. OF SLICE
C                K    = AT RETURN, SOIL TYPE AT BASE OF SLICE
C                WSLC = AT RETURN, WEIGHT OF SLICE/UNIT WIDTH
C
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON
C     -----------------------------------------------------------------
      DIMENSION JSTORE(9), YY1(10), YY2(10)
      COMMON DUM1(26),NBND,IDUM1,ITP(15),IDUM2(4),BNDS(20,4),EQ(20,2)
      COMMON GAMMA(15),DUM2(83),Y1(10)
      N1=1
      N2=1
C     ------------------------------------
C     FIND ALL R.H.S. INTERSECTIONS
C     ------------------------------------
      DO 55 J=1,NBND
         Y=XR*EQ(J,1)+EQ(J,2)
         IF (XR-BNDS(J,1)) 55,15,5
5        IF (XR-BNDS(J,3)) 10,20,55
10       IF (Y-YR) 55,25,40
15       IF (Y-YR) 55,30,45
20       IF (Y-YR) 55,35,50
25       IF (EQ(J,1)-TNP) 50,55,45
30       IF (EQ(J,1)-TNP) 55,55,45
35       IF (EQ(J,1)-TNP) 50,55,55
40       YY1(N1)=Y
         JSTORE(N1)=ITP(J)
         N1=N1+1
45       YY2(N2)=Y
         N2=N2+1
         GO TO 55
C
50       YY1(N1)=Y
         JSTORE(N1)=ITP(J)
         N1=N1+1
55    CONTINUE
      YY1(N1)=YR
      YY2(N2)=YR
C     ------------------------------------
C     CALCULATE WEIGHT OF SLICE
C     ------------------------------------
      WSLC=0.0
      DO 60 J=2,N1
         K=JSTORE(J-1)
60    WSLC=WSLC+.5*GAMMA(K)*(YY1(J-1)+Y1(J-1)-YY1(J)-Y1(J))
      YTL=Y1(1)
C     ------------------------------------
C     RESTORE R.H.S. INTERSECTIONS FOR NEXT SLICE
C     ------------------------------------
      DO 65 J=1,N2
65    Y1(J)=YY2(J)
      RETURN
      END
```

STATEMENT NUMBER	DEFINITION	REFERENCES
5	10.	9.
10	11.	10.
15	12.	9.
20	13.	10.
25	14.	11.
30	15.	12.
35	16.	13.
40	17.	11.
45	20.	12. 14. 15.
50	23.	13. 14. 16.
55	26.	7. 9. 10. 11. 12. 13. 14. 15. 16. 22.
60	32.	30.
65	35.	34.

LABEL	TYPE	DEFINITION	REFERENCES
HNDS	R	3. CD	9. 10.
DUM1	R	3. CD	
DUM2	R	4. CD	
EO	R	3. CD	8. 14. 15. 16.
GAMMA	R	4. CD	32.
IDUM1	I	3. C	
IDUM2	I	3. CD	
ITP	I	3. CD	18. 24.
J	I	7.	8. 9. 10. 14. 15. 16. 18. 24. 30. 31. 32. 34. 35.
JSTORE	I	2. D	18. 24. 31.
K	I	1.	31. 32.
NBNO	I	3. C	7.
N1	I	5.	17. 18. 19. 23. 24. 25. 27. 30.
N2	I	6.	20. 21. 28. 34.
TNP	R	1.	14. 15. 16.
WSLC	R	1.	29. 32.
XR	R	1.	8. 9. 10.
Y	R	8.	11. 12. 13. 17. 20. 23.
YR	R	1.	11. 12. 13. 27. 28.
Y1L	R	1.	33.
YY1	R	2. D	17. 23. 27. 32.
YY2	R	2. D	20. 28. 35.
Y1	R	4. CD	32. 33. 35.

FORSTAT Listing of Subroutine RADIUS

```
      SUBROUTINE RADIUS (XCEN,YCEN,RAD,I)
C     ------------------------------------------------------------------
C                             SUBROUTINE RADIUS
C     ------------------------------------------------------------------
C     PURPOSE-
C          TO BUILD ARRAY OF RADII THAT ARE TANGENT TO LOWER BOUNDARIES.
C     THE MAXIMUM RADIUS IS THE MINIMUM OF THOSE THAT ARE TANGENT TO
C     BOUNDARIES WITH ITP=0.
C     ------------------------------------------------------------------
C     USAGE-
C          CALL RADIUS(XCEN,YCEN,RAD,I)
C
C          WHERE  XCEN = X-COORD. OF CIRCLE CENTER
C                 YCEN = Y-COORD. OF CIRCLE CENTER
C                 RAD  = ARRAY OF RADII
C                 I    = NUMBER OF RADII
C
C          ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON
C     ------------------------------------------------------------------
C     SYSTEM ROUTINES-
C          FUNCTION SQRT
C     ------------------------------------------------------------------
      DIMENSION RAD(15)
      COMMON DUM1(21),XTOE,YTOE,XTOP,YTOP,DUM2,NBND,NTOP,ITP(15)
      COMMON IDUM(4),BNDS(20,4),EQ(20,2)
      EQUIVALENCE (XI,TEMP), (MTOP,II)
      R(A,B)=SQRT((XCEN-A)**2+(YCEN-B)**2)
      RMAX=999999.
      RAD(1)=R(XTOE,YTOE)
      TEMP=R(XTOP,YTOP)
      IF (RAD(1)-TEMP) 5,10,10
    5 RAD(1)=TEMP
   10 MTOP=NTOP+1
      I=1
C     ---------------------------------
C     FIND ALL TANGENTS TO LOWER BOUNDARIES
C     ---------------------------------
      DO 50 J=MTOP,NBND
         XI=(XCEN+EQ(J,1)*(YCEN-EQ(J,2)))/(EQ(J,1)*EQ(J,1)+1.)
         IF (XI-BNDS(J,1)) 50,15,15
   15    IF (XI-BNDS(J,3)) 20,50,50
   20    YI=EQ(J,1)*XI+EQ(J,2)
         IF (YI-BNDS(J,2)) 30,35,25
   25    IF (YI-BNDS(J,4)) 35,50,50
   30    IF (YI-BNDS(J,4)) 50,50,35
   35    I=I+1
         RAD(I)=R(XI,YI)
         IF (ITP(J)) 40,40,50
   40    IF (RAD(I)-RMAX) 45,50,50
   45    RMAX=RAD(I)
   50 CONTINUE
      II=I-1
C     ---------------------------------
C     ORDER  RAD  ARRAY
C     ---------------------------------
      DO 60 J=1,II
         K=J+1
      DO 60 JJ=K,I
         IF (RAD(J)-RAD(JJ)) 60,60,55
   55    TEMP=RAD(J)
         RAD(J)=RAD(JJ)
         RAD(JJ)=TEMP
   60 CONTINUE
C     ---------------------------------
C     INSURE DESIRED (ITP=0) MAXIMUM
C     ---------------------------------
      DO 65 JJ=1,I
         J=I-JJ+1
         IF (RAD(J)-RMAX) 70,70,65
   65 CONTINUE
   70 I=J
      RETURN
      END
```

STATEMENT NUMBER	DEFINITION	REFERENCES						
5	11.	10.						
10	12.	10.						
15	17.	16.						
20	18.	17.						
25	20.	19.						
30	21.	19.						
35	22.	19.	20.	21.				
40	25.	24.						
45	26.	25.						
50	27.	14.	16.	17.	20.	21.	24.	25.
55	33.	32.						
60	36.	29.	31.	32.				
65	40.	37.	39.					
70	41.	39.						

LABEL	TYPE	DEFINITION		REFERENCES						
A	R	6.								
B	R	6.								
BNDS	R	4. CD		16.	17.	19.	20.	21.		
DUM1	R	3. CD								
DUM2	R	3. C								
EQ	R	4. CD		15.	18.					
I	I	1.		13.	22.	23.	25.	26.	28.	31.
				37.	38.	41.				
IDUM	I	4. CD								
II	I	5. E		28.	29.					
ITP	I	3. CD		24.						
J	I	14.		15.	16.	17.	18.	19.	20.	21.
				24.	29.	30.	32.	33.	34.	38.
				39.	41.					
JJ	I	31.		32.	34.	35.	37.	38.		
K	I	30.		31.						
MTOP	I	5. E		12.	14.					
NBND	I	3. C		14.						
NTOP	I	3. C		12.						
R	R ASF	6.		8.	9.	23.				
RAD	R	1. D		2.	8.	10.	11.	23.	25.	26.
				32.	33.	34.	35.	39.		
RMAX	R	7.		25.	26.	39.				
SQRT	R	6.	FUNCTION							
TEMP	R	5. E		9.	10.	11.	33.	35.		
XCEN	R	1.		6.	15.					
XI	R	5. E		15.	16.	17.	18.	23.		
XTOE	R	3. C		8.						
XTOP	R	3. C		9.						
YCEN	R	1.		6.	15.					
YI	R	18.		19.	20.	21.	23.			
YTOE	R	3. C		8.						
YTOP	R	3. C		9.						

FORSTAT Listing of Function HEAD

```
 1.         FUNCTION HEAD (XD,YD)                                              HD   2
      C   ---------------------------------------------------------------------HD   4
      C                             FUNCTION HEAD                              HD   6
      C   ---------------------------------------------------------------------HD   8
      C   PURPOSE-                                                             HD  10
      C        TO CALCULATE TOTAL HEAD AT POINT (XD,YD) USING FIFTH ORDER      HD  12
      C   POLYNOMIAL COEFFICIENTS GENERATED BY PROGRAM FLWNET.                 HD  14
      C   ---------------------------------------------------------------------HD  16
      C   USAGE-                                                               HD  18
      C        TOTAL HEAD = HEAD(XD,YD)                                        HD  20
      C                                                                        HD  22
      C        WHERE  XD = X-COORD. OF FLOW DOMAIN                             HD  24
      C               YD = Y-COORD. OF FLOW DOMAIN                             HD  26
      C                                                                        HD  28
      C        ALL OTHER VARIABLES ARE SUPPLIED THROUGH BLANK COMMON           HD  30
      C   ---------------------------------------------------------------------HD  32
 2.         COMMON A(21)                                                       HD  34
 3.         XD2=XD*XD                                                          HD  36
 4.         XD3=XD2*XD                                                         HD  38
 5.         XD4=XD3*XD                                                         HD  40
 6.         YD2=YD*YD                                                          HD  42
 7.         YD3=YD2*YD                                                         HD  44
 8.         YD4=YD3*YD                                                         HD  46
 9.         PT=A(1)+XD*A(2)+YD*A(3)+XD2*A(4)+XD*YD*A(5)+YD2*A(6)+XD3*A(7)      HD  48
10.         PT=PT+XD2*YD*A(8)+XD*YD2*A(9)+YD3*A(10)+XD4*A(11)+XD3*YD*A(12)     HD  50
11.         PT=PT+XD2*YD2*A(13)+XD*YD3*A(14)+YD4*A(15)+XD4*XD*A(16)            HD  52
12.         PT=PT+XD4*YD*A(17)+XD3*YD2*A(18)+XD2*YD3*A(19)+XD*YD4*A(20)        HD  54
13.         HEAD=PT+YD*YD4*A(21)                                               HD  56
14.         RETURN                                                             HD  58
15.         END                                                                HD  60-
```

LABEL	TYPE	DEFINITION	REFERENCES						
A	R	2. CD	9.	10.	11.	12.	13.		
HEAD	R	13.							
PT	R	9.	10.	11.	12.	13.			
XD	R	1.	3.	4.	5.	9.	10.	11.	12.
XD2	R	3.	4.	9.	10.	11.	12.		
XD3	R	4.	5.	9.	10.	12.			
XD4	R	5.	10.	11.	12.				
YD	R	1.	6.	7.	8.	9.	10.	12.	13.
YD2	R	6.	7.	9.	10.	11.	12.		
YD3	R	7.	8.	10.	11.	12.			
YD4	R	8.	11.	12.	13.				

APPENDIX B

EXAMPLE PROBLEM

APPENDIX B

EXAMPLE PROBLEM

Each main program deck has been provided with test data. The purpose of the test data is twofold: (1) to illustrate several of the available options; (2) to serve as a check for duplicated decks.

Two slope profiles are shown in Figure 14. Slope A is used by examples 1, 2, and 3. In example 1, the Taylor equation (SLOPE1) is used. The soil profile is considered in a dry condition, and a grid search was specified. For each grid center, the factor of safety of all circles generated by the radius increment value is printed in addition to the statement of the minimum. By examining at each center the variation of F as the radius is increased, the designer may conclude whether a "good" value of the radius increment value was chosen. Once the validity of the minimum factors of safety at each center is decided, a contour map of F can be made to determine the "local" minimum factor of safety. In example 1, this minimum factor of safety is at (140,60) and equals 2.169.

Program SLOPE2 was used in the second example. The same grid was analyzed but for the condition of a water table, where the pressure heads are assumed equal to the vertical distance to the water table. However, this analysis was incomplete. Upon examining a contour map of the grid, one can readily see that the contours do

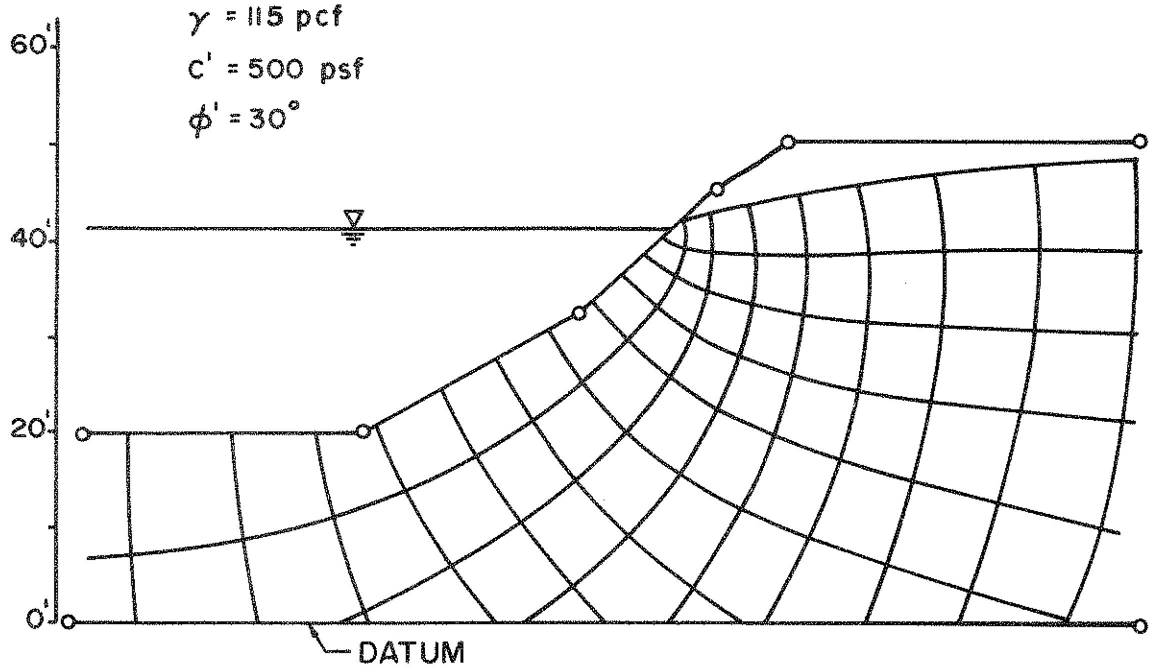

Figure 14 a - Example Profile A

	γ pcf	c psf	φ °
1	130	1300	
2	130	1200	
3	120	450	
4	130		30

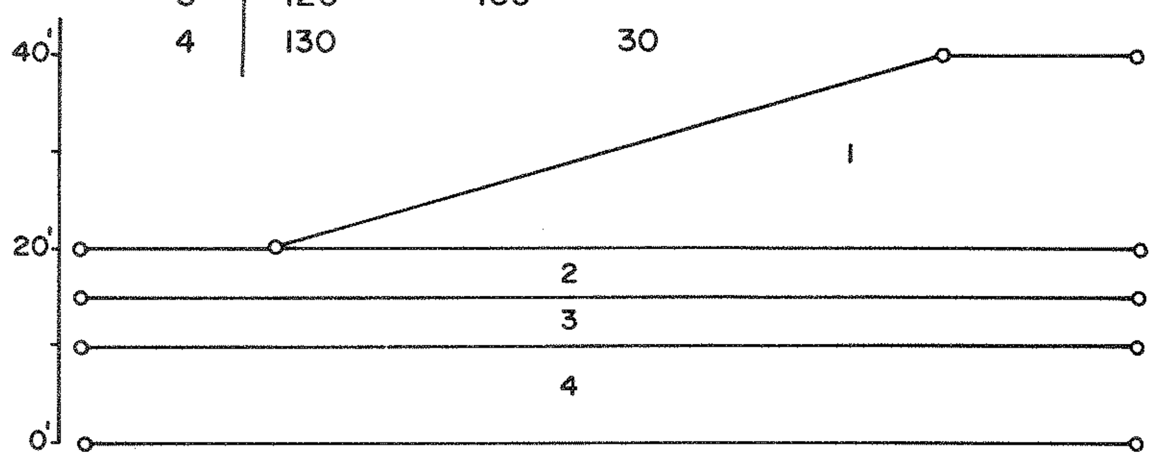

Figure 14 b - Example Profile B

not close. Therefore, the magnitude of the minimum is still unknown, and another grid would have to be analyzed.

The third example illustrates an analysis of profile A using the flow net. Program SLOPE3 is used for this example. The fifth order polynomial used to approximate the flow net was first calculated by program FLWNET. Also, in this example, the individual circle option was used.

The fifth example uses program SLOPE4, the irregular search, to analyze slope B. To locate the minimum factor of safety for the irregular search, the following procedure is recommended. For each NLAYER and X-EXIT determine the minimum factor of safety. Prepare a contour map of F over the two parameters NLAYER and X-EXIT to locate the minimum F of the search. Run two more searches using different values of X-CONTROL to determine the minimum F of the profile.

Example Problem 1 - Input

```
 EXAMPLE 1   SLOPE A--DRY CONDITION
 6 5 1  0               129.0      20.0        174.0      50.0
  0.0      20.0         129.0      20.0        1
129.0      20.0         151.0      32.0        1
151.0      32.0         167.0      47.0        1
167.0      47.0         174.0      50.0        1
174.0      50.0         300.0      50.0        1
  0.0       0.0         300.0       0.0        0
115.0     500.0          30.0
2 1
150.0     130.0          70.0      50.0        10.0        3 3
END
```

Example Problem 1 - Output

```
                 ---SLOPE STABILITY ANALYSIS---
                   TAYLOR  METHOD OF SLICES


   PROBLEM DESCRIPTION       EXAMPLE 1   SLOPE A--DRY CONDITION


PROFILE PARAMETERS

   TOE COORDINATES                         CREST COORDINATES

      XTOE =      129.0                       XTOP =      174.0
      YTOE =       20.0                       YTOP =       50.0


  BOUNDARY COORDINATES

      5 TOP    BOUNDARIES
      6 TOTAL  BOUNDARIES

     BND NO.    X-LEFT     Y-LEFT     X-RIGHT    Y-RIGHT     SOIL TYPE BELOW
        1         0.0       20.0      129.0       20.0              1
        2       129.0       20.0      151.0       32.0              1
        3       151.0       32.0      167.0       47.0              1
        4       167.0       47.0      174.0       50.0              1
        5       174.0       50.0      300.0       50.0              1
        6         0.0        0.0      300.0        0.0              0


  SOIL PROPERTIES

      1 TYPES OF SOIL

         TYPE NO.    GAMMA       C         PHI
            1        115.0     500.0      30.0


  TOP BOUNDARY LOADING

      -0 UNIFORM LOADING

      -0 CONCENTRATED LOADING


  NO G.W.L. HAS BEEN SPECIFIED
```

```
GRID OPTION SPECIFIED
        1 GRIDS TO BE ANALYZED


   GRID SPECIFICATIONS

     XMAX =      150.0           YMAX =      70.0
     XMIN =      130.0           YMIN =      50.0
     ICOL =          3           IROW =         3

     RADIUS INCREMENT =      10.0

 X-CENTER      Y-CENTER      RADIUS          FS


   130.0         70.0
                              50.01         2.464
                              60.01         2.601
                              70.00         2.960
       MINIMUM FS FOR THIS CENTER =         2.464
   140.0         70.0
                              51.20         2.184
                              61.20         2.511
                              70.00         2.877
       MINIMUM FS FOR THIS CENTER =         2.184
   150.0         70.0
                              54.23         2.448
                              64.23         2.754
                              70.00         2.991
       MINIMUM FS FOR THIS CENTER =         2.448


   130.0         60.0
                              45.12         2.737
                              55.12         2.792
                              60.00         2.958
       MINIMUM FS FOR THIS CENTER =         2.737
   140.0         60.0
                              41.68         2.169
                              51.68         2.453
                              60.00         2.907
       MINIMUM FS FOR THIS CENTER =         2.169
   150.0         60.0
                              45.18         2.377
                              55.18         2.701
                              60.00         2.897
       MINIMUM FS FOR THIS CENTER =         2.377


   130.0         50.0
                              44.00         3.033
                              50.00         3.103
       MINIMUM FS FOR THIS CENTER =         3.033
   140.0         50.0
                              34.00         2.356
                              44.00         2.563
                              50.00         2.902
       MINIMUM FS FOR THIS CENTER =         2.356
   150.0         50.0
                              36.62         2.395
                              46.62         2.726
                              50.00         2.869
       MINIMUM FS FOR THIS CENTER =         2.395
```

Example Problem 2 - Input

```
 EXAMPLE 2    SLOPE A--WATER TABLE
 6 5 1  10              129.0      20.0        174.0      50.0
  0.0     20.0          129.0      20.0          1
129.0     20.0          151.0      32.0          1
151.0     32.0          167.0      47.0          1
167.0     47.0          174.0      50.0          1
174.0     50.0          300.0      50.0          1
  0.0      0.0          300.0       0.0          0
115.0    500.0           30.0
  0.0     41.0
160.0     41.0
163.0     42.0
165.0     43.0
168.5     44.0
174.0     45.0
180.0     46.0
210.      49.0
300.0     50.0
2 1
150.0    130.0      70.0      50.0      10.0      3 3
END
```

Example Problem 2 - Output

```
**SLOPE STABILITY ANALYSIS**
MODIFIED BISHOP METHOD OF SLICES
MOMENT CENTER = CIRCLE CENTER
```

PROBLEM DESCRIPTION   EXAMPLE 2   SLOPE A--WATER TABLE

PROFILE PARAMETERS

TOE COORDINATES

XTOE = 129.0
YTOE = 20.0

CREST COORDINATES

XTOP = 174.0
YTOP = 50.0

BOUNDARY COORDINATES

5 TOP BOUNDARIES
6 TOTAL BOUNDARIES

BND NO.	X-LEFT	Y-LEFT	X-RIGHT	Y-RIGHT	SOIL TYPE BELOW
1	0.0	20.0	129.0	20.0	1
2	129.0	20.0	151.0	32.0	1
3	151.0	32.0	167.0	47.0	1
4	167.0	47.0	174.0	50.0	1
5	174.0	50.0	300.0	50.0	1
6	0.0	0.0	300.0	0.0	0

SOIL PROPERTIES

1 TYPES OF SOIL

TYPE NO.	GAMMA	C	PHI
1	115.0	500.0	30.0

TOP BOUNDARY LOADING

=0 UNIFORM LOADING

=0 CONCENTRATED LOADING

G.W.L. SPECIFIED BY 9 COORDINATE POINTS

NO.	X-GWL	Y-GWL
1	0.00	41.00
2	160.00	41.00
3	163.00	42.00
4	165.00	43.00
5	168.50	44.00
6	174.00	45.00
7	180.00	46.00
8	210.00	49.00
9	300.00	50.00

VERTICAL DISTANCE TO G.W.L. SET EQUAL TO PRESSURE

```
GRID OPTION SPECIFIED
        1 GRIDS TO BE ANALYZED



    GRID SPECIFICATIONS

     XMAX =      150.0          YMAX =      70.0
     XMIN =      130.0          YMIN =      50.0
     ICOL =          3          IROW =         3

     RADIUS INCREMENT =      10.0

  X-CENTER     Y-CENTER      RADIUS          FS


    130.0        70.0
                              50.01        3.278
                              60.01        3.222
                              70.00        3.477
       MINIMUM FS FOR THIS CENTER =        3.222

    140.0        70.0
                              51.20        2.498
                              61.20        2.854
                              70.00        3.212
       MINIMUM FS FOR THIS CENTER =        2.498

    150.0        70.0
                              54.23        2.567
                              64.23        2.932
                              70.00        3.178
       MINIMUM FS FOR THIS CENTER =        2.567



    130.0        60.0
                              45.12        3.924
                              55.12        3.560
                              60.00        3.663
       MINIMUM FS FOR THIS CENTER =        3.560

    140.0        60.0
                              41.48        2.654
                              51.48        2.923
                              60.00        3.267
       MINIMUM FS FOR THIS CENTER =        2.654

    150.0        60.0
                              45.18        2.599
                              55.18        2.977
                              60.00        3.100
       MINIMUM FS FOR THIS CENTER =        2.599



    130.0        50.0
                              44.00        4.306
                              50.00        4.137
       MINIMUM FS FOR THIS CENTER =        4.137

    140.0        50.0
                              34.00        3.165
                              44.00        3.214
                              50.00        3.434
       MINIMUM FS FOR THIS CENTER =        3.165

    150.0        50.0
                              36.62        2.730
                              46.62        3.123
                              50.00        3.280
       MINIMUM FS FOR THIS CENTER =        2.730
```

Example Problem 3 - Input

```
 EXAMPLE 3    SLOPE A--FLORNET
 5 5 1  29   0.0
   0.0      20.0      129.0      20.0       1
 129.0      20.0      151.0      32.0       1
 151.0      32.0      167.0      47.0       1
 167.0      47.0      174.0      50.0       1
 174.0      50.0      300.0      50.0       1
 115.0     500.0       30.0
   0.0      41.0
 160.0      41.0
 163.0      42.0
 165.0      43.0
 168.5      44.0
 174.0      45.0
 180.0      46.0
 210.       49.0
 300.0      50.0
-1.635E+02
 6.196E+00
 7.346E+00
-7.498E-02
-1.254E-01
-2.155E-01
 4.542E-04
 5.374E-04
 5.063E-03
-4.609E-03
-1.367E-06
 4.899E-07
-3.694E-05
 5.078E-05
-6.651E-07
 1.665E-09
-4.786E-09
 7.955E-08
-1.273E-07
-4.890E-08
 8.549E-09
 1 6
 130.0      60.0      45.13
 140.0      60.0      41.49
 150.0      60.0      45.19
 130.0      70.0      50.02
 140.0      70.0      51.21
 150.0      70.0      54.24
 END
```

Example Problem 3 - Output

```
                  --SLOPE STABILITY ANALYSIS--
                MODIFIED BISHOP METHOD OF SLICES
                    MOMENT CENTER = +Y INF


   PROBLEM DESCRIPTION      EXAMPLE 3   SLOPE A--FLORNET


PROFILE PARAMETERS

    TOE COORDINATES                        CREST COORDINATES

        XTOE =       -0.0                      XTOP =       -0.0
        YTOE =       -0.0                      YTOP =       -0.0


    BOUNDARY COORDINATES

        5 TOP    BOUNDARIES
        5 TOTAL  BOUNDARIES

      BND NO.     X-LEFT    Y-LEFT    X-RIGHT    Y-RIGHT    SOIL TYPE BELOW
         1          0.0      20.0      129.0      20.0            1
         2        129.0      20.0      151.0      32.0            1
         3        151.0      32.0      167.0      47.0            1
         4        167.0      47.0      174.0      50.0            1
         5        174.0      50.0      300.0      50.0            1
```

SOIL PROPERTIES

1 TYPES OF SOIL

TYPE NO.	GAMMA	C	PHI
1	115.0	500.0	30.0

TOP BOUNDARY LOADING

-0 UNIFORM LOADING

-0 CONCENTRATED LOADING

G.W.L. SPECIFIED BY 9 COORDINATE POINTS

NO.	X-GWL	Y-GWL
1	0.00	41.00
2	160.00	41.00
3	163.00	42.00
4	165.00	43.00
5	168.50	44.00
6	174.00	45.00
7	180.00	46.00
8	210.00	49.00
9	300.00	50.00

FIFTH ORDER POLYNOMIAL APPROXIMATES FLOW NET

I	A(I)
1	-1.635E+02
2	6.196E+00
3	7.346E+00
4	-7.498E-02
5	-1.254E-01
6	-2.155E-01
7	4.542E-04
8	5.374E-04
9	5.063E-03
10	-4.809E-03
11	-1.367E-06
12	4.899E-07
13	-3.604E-05
14	5.078E-05
15	-6.651E-07
16	1.645E-09
17	-4.786E-09
18	7.955E-08
19	-1.273E-07
20	-4.880E-08
21	8.549E-08

INDIVIDUAL CIRCLE OPTION SPECIFIED
6 CIRCLES TO BE ANALYZED

X-CENTER	Y-CENTER	RADIUS	FS
130.0	60.0	45.13	3.209
140.0	60.0	41.49	2.282
150.0	60.0	45.19	2.197
130.0	70.0	50.02	2.889
140.0	70.0	51.21	2.198
150.0	70.0	54.24	2.230

Example Problem 4 - Input

```
 EXAMPLE 4   SLOPE B--IRREGULAR SEARCH
 6 3 4                  200.       10.       270.       30.
   0.0      10.0       200.0       10.0        2
 200.0      10.0       270.0       30.0        1
 270.0      30.0      1000.0       30.0        1
 200.0      10.0      1000.0       10.0        2
   0.0       5.0      1000.0        5.0        3
   0.0      0.0       1000.0        0.0        4
 130.0    1000.0        0.0
 130.0    1200.0        0.0
 120.0     450.0        0.0
 130.0        0.0    30.0
 2 1
 30.0      0.0        320.0       280.0       210.0       6 7 3
 END
```

Example Problem 4 - Output

```
                 --SLOPE STABILITY ANALYSIS--
                 MODIFIED BISHOP METHOD OF SLICES
                     MOMENT CENTER = +Y INF

     PROBLEM DESCRIPTION      EXAMPLE 4  SLOPE B--IRREGULAR SEARCH


PROFILE PARAMETERS

    TOE COORDINATES                          CREST COORDINATES

        XTOE =      200.0                        XTOP =      270.0
        YTOE =       10.0                        YTOP =       30.0


    BOUNDARY COORDINATES

         3 TOP    BOUNDARIES
         6 TOTAL  BOUNDARIES

        BND NO.     X-LEFT     Y-LEFT     X-RIGHT     Y-RIGHT     SOIL TYPE BELOW
           1          0.0       10.0       200.0       10.0             2
           2        200.0       10.0       270.0       30.0             1
           3        270.0       30.0      1000.0       30.0             1
           4        200.0       10.0      1000.0       10.0             2
           5          0.0        5.0      1000.0        5.0             3
           6          0.0        0.0      1000.0        0.0             4


    SOIL PROPERTIES

        4 TYPES OF SOIL

            TYPE NO.     GAMMA        C          PHI
               1         140.0     1000.0        0.0
               2         130.0     1200.0        0.0
               3         120.0      450.0        0.0
               4         130.0        0.0       30.0


    TOP BOUNDARY LOADING

        -0 UNIFORM LOADING

        -0 CONCENTRATED LOADING


    NO G.W.L. HAS BEEN SPECIFIED
```

SEARCH IRREGULAR SURFACE OPTION SPECIFIED
1 SEARCHES TO BE ANALYZED

SEARCH SPECIFICATIONS

XMIN = 280.0 YMIN = 0.0
NSUR = 3
XMAX = 320.0 YMAX = 30.0

X-CONTROL = 210.0

NMIN = 6
NMAX = 7

NLAYER = 6

X-EXIT	B	FS	(X(I),Y(I)),....					
320.00	30	2.857	192.68	10.00	210.00	0.00	226.41	1.02
			250.45	4.02	275.96	8.79	295.90	15.00
			310.41	22.24	320.00	30.00		
320.00	45	2.751	200.00	10.00	210.00	0.00	226.41	1.02
			250.45	4.02	275.96	8.79	295.90	15.00
			310.41	22.24	320.00	30.00		
320.00	60	2.924	203.63	11.04	210.00	0.00	226.41	1.02
			250.45	4.02	275.96	8.79	295.90	15.00
			310.41	22.24	320.00	30.00		
300.00	30	2.603	192.68	10.00	210.00	0.00	223.42	1.02
			243.10	4.02	263.97	8.79	280.28	15.00
			292.16	22.24	300.00	30.00		
300.00	45	2.590	200.00	10.00	210.00	0.00	223.42	1.02
			243.10	4.02	263.97	8.79	280.28	15.00
			292.16	22.24	300.00	30.00		
300.00	60	2.770	203.63	11.04	210.00	0.00	223.42	1.02
			243.10	4.02	263.97	8.79	280.28	15.00
			292.16	22.24	300.00	30.00		
280.00	30	2.651	192.68	10.00	210.00	0.00	220.44	1.02
			235.74	4.02	251.97	8.79	264.66	15.00
			273.90	22.24	280.00	30.00		
280.00	45	2.638	200.00	10.00	210.00	0.00	220.44	1.02
			235.74	4.02	251.97	8.79	264.66	15.00
			273.90	22.24	280.00	30.00		
280.00	60	2.846	203.63	11.04	210.00	0.00	220.44	1.02
			235.74	4.02	251.97	8.79	264.66	15.00
			273.90	22.24	280.00	30.00		

NLAYER = 7

X-EXIT	B	FS	(X(I),Y(I)),....					
320.00	30	2.686	192.68	10.00	210.00	0.00	274.99	.75
			247.10	2.97	270.84	6.55	289.77	11.30
			303.94	16.98	313.66	23.32	320.00	30.00
320.00	45	2.676	200.00	10.00	210.00	0.00	274.99	.75
			247.10	2.97	270.84	6.55	289.77	11.30
			303.94	16.98	313.66	23.32	320.00	30.00
320.00	60	2.843	203.63	11.04	210.00	0.00	274.99	.75
			247.10	2.97	270.84	6.55	289.77	11.30
			303.94	16.98	313.66	23.32	320.00	30.00
300.00	30	2.535	192.68	10.00	210.00	0.00	272.26	.75
			240.35	2.97	259.78	6.55	275.27	11.30
			286.86	16.98	294.82	23.32	300.00	30.00
300.00	45	2.522	200.00	10.00	210.00	0.00	272.26	.75
			240.35	2.97	259.78	6.55	275.27	11.30
			286.86	16.98	294.82	23.32	300.00	30.00
300.00	60	2.694	203.63	11.04	210.00	0.00	272.26	.75
			240.35	2.97	259.78	6.55	275.27	11.30
			286.86	16.98	294.82	23.32	300.00	30.00
280.00	30	2.574	192.68	10.00	210.00	0.00	219.56	.75
			233.61	2.97	248.72	6.55	260.77	11.30
			269.78	16.98	275.97	23.32	280.00	30.00
280.00	45	2.559	200.00	10.00	210.00	0.00	219.54	.75
			233.61	2.97	248.72	6.55	260.77	11.30
			269.78	16.98	275.97	23.32	280.00	30.00
280.00	60	2.755	203.63	11.04	210.00	0.00	219.56	.75
			233.61	2.97	248.72	6.55	260.77	11.30
			269.78	16.98	275.97	23.32	280.00	30.00

Example Output of FLWNET

FIFTH ORDER POLYNOMIAL APPROXIMATION FOR FLOWNET--

THE EQUATION HAS THE FOLLOWING FORM

```
EST. H = A1 + A2(X) + A3(Y) + A4(X**2) + A5(X)(Y) + A6(Y**2) +
         A7(X**3) + A8(X**2)(Y) + A9(X)(Y**2) + A10(Y**3) +
         A11(X**4) + A12(X**3)(Y) + A13(X**2)(Y**2) +
         A14(X)(Y**3) + A15(Y**4) + A16(X**5) + A17(X**4)(Y) +
         A18(X**3)(Y**2) + A19(X**2)(Y**3) + A20(X)(Y**4) + A21(Y**5).
```

I	AI
1	-1.635E+02
2	6.196E+00
3	7.346E+00
4	-7.498E-02
5	-1.254E-01
6	-2.155E-01
7	4.542E-04
8	5.374E-04
9	5.063E-03
10	-4.609E-03
11	-1.367E-06
12	4.899E-07
13	-3.604E-05
14	5.078E-05
15	-6.651E-07
16	1.645E-09
17	-4.786E-09
18	7.955E-08
19	-1.273E-07
20	-4.880E-08
21	8.549E-08

ORIGINAL AND COMPUTED VALUES

PT.NO.	X	Y	H	EST. H	RESIDUAL
1	100.000	20.000	41.000	40.968	-.032
2	104.000	20.000	41.000	41.029	.029
3	115.000	20.000	41.000	41.029	.029
4	124.000	20.000	41.000	41.063	.063
5	130.000	20.500	41.000	41.092	.092
6	137.000	24.000	41.000	40.772	-.228
7	142.500	27.500	41.000	40.565	-.435
8	148.000	30.500	41.000	40.703	-.297
9	152.500	33.500	41.000	40.914	-.086
10	155.000	37.000	41.000	40.822	-.178
11	157.500	39.000	41.000	41.112	.112
12	160.000	41.000	41.000	41.512	.512
13	105.000	7.000	42.000	41.908	-.092
14	116.000	9.000	42.000	42.124	.124
15	125.500	11.000	42.000	42.074	.074
16	133.500	14.000	42.000	41.984	-.016
17	141.000	17.500	42.000	41.963	-.037
18	146.500	21.000	42.000	41.981	-.019
19	152.000	25.000	42.000	42.087	.087
20	157.000	29.000	42.000	42.301	.301
21	159.500	33.000	42.000	42.278	.270
22	161.500	36.500	42.000	42.293	.293
23	162.000	39.000	42.000	42.177	.177
24	163.000	42.000	42.000	42.211	.211
25	129.000	1.000	43.000	42.997	-.003
26	137.500	6.000	43.000	42.836	-.164
27	145.000	10.000	43.000	42.884	-.116
28	151.000	15.000	43.000	42.912	-.088
29	156.000	20.000	43.000	42.999	-.001
30	161.000	25.000	43.000	43.216	.216
31	163.000	30.000	43.000	43.119	.119
32	164.500	35.000	43.000	42.993	-.007
33	165.000	38.500	43.000	42.862	-.138
34	165.000	43.000	43.000	42.682	-.318
35	144.000	0.000	44.000	44.054	.054

36	150.000	3.500	44.000	44.030	.030
37	156.500	9.000	44.000	43.940	-.060
38	162.000	15.000	44.000	44.034	.034
39	166.000	22.000	44.000	44.070	.070
40	168.000	27.500	44.000	44.031	.031
41	168.500	44.000	44.000	43.540	-.460
42	169.500	33.000	44.000	43.975	-.025
43	170.000	38.500	44.000	43.856	-.144
44	163.000	3.500	45.000	45.071	.071
45	168.000	12.000	45.000	44.946	-.054
46	171.500	19.500	45.000	44.931	-.069
47	173.000	25.500	45.000	44.847	-.153
48	174.500	32.000	45.000	44.813	-.187
49	175.000	38.000	45.000	44.763	-.237
50	174.000	45.000	45.000	44.798	-.202
51	170.000	0.000	46.000	45.893	-.107
52	175.500	9.000	46.000	46.019	.019
53	179.000	17.000	46.000	46.030	.030
54	180.000	46.000	46.000	45.994	-.006
55	181.000	24.000	46.000	46.017	.017
56	181.500	31.000	46.000	45.888	-.112
57	181.500	38.500	46.000	45.816	-.184
58	183.000	6.000	47.000	46.990	-.010
59	186.000	14.500	47.000	46.996	-.004
60	187.000	23.000	47.000	46.833	-.167
61	188.000	47.000	47.000	47.223	.223
62	189.000	31.000	47.000	46.922	-.078
63	189.000	39.000	47.000	46.883	-.117
64	192.000	3.000	48.000	47.957	-.043
65	195.000	13.000	48.000	48.017	.017
66	197.000	22.000	48.000	47.995	-.005
67	197.500	48.000	48.000	48.177	.177
68	198.500	30.500	48.000	48.066	.066
69	199.000	39.000	48.000	48.058	.058
70	202.000	0.000	49.000	48.982	-.018
71	205.000	10.000	49.000	48.974	-.026
72	207.500	21.000	49.000	48.864	-.136
73	209.000	30.000	49.000	49.033	.033
74	209.000	39.000	49.000	49.004	.004
75	210.000	49.000	49.000	48.807	-.193

STATISTICAL VALUES

PERCENT SS = 86.722657
R-SQUARED = .867227
R = .931250

APPENDIX C

LIST OF SYMBOLS

APPENDIX C

LIST OF SYMBOLS

a	Point of application of N' measured from left side of slice
$\bar{a}$	Equals $(\bar{y} - h)$
b	Point of application of E measured from base of slice
$c'_a(c_a)$	Effective (total) stress Mohr-Coulomb strength intercept
$C'_a(C_a)$	Effective (total) force when the unit value is $c'_a(c_a)$
$E'(E)$	Effective (total normal force on side of slice
F	Factor of safety (strength reduction factor)
F_T	Factor of Safety in the Taylor Method of Slices
F_{MB}	Factor of Safety in the Modified Bishop Method of Slices
h	Average height of slice
i	Subscript denoting a particular slice
$\bar{k}$	Equals $(1 - \frac{h}{\bar{y}})$
$N'(N)$	Effective (total) normal force on base of slice
R	Radius of assumed failure surface; Resultant force on slice side
S_a	Available shear force on base of slice
S_r	Required (for equilibrium) shear force on base of slice
T_k	Terms in Fibonacci sequence
t	Width of slice
U_α	Water force on base of slice
U_β	Water force on top of slice

U	Water force on interslice side
$W'(W)$	Submerged (total) weight of slice
W_w	Equivalent water weight of slice
X	Shear force on side of slice
$\bar{x}$	Distance in the x-direction from the center of the slice base to a moment center
$\bar{y}$	Distance in the y-direction from the center of the slice base to a moment center
α	Angle of inclination of base of slice
β	Angle of inclination of top of slice
γ	Total unit weight
$\phi'(\phi)$	Effective (total) stress Mohr-Coulomb strength angle
θ	Central angle of circular failure surface
$\tau_r(\tau_a)$	Shear stress required (available)
$\sigma'(\sigma)$	Effective (total) normal stress